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THE RELATION OF ORE-DEPOSITION TO PHYSICAL CONDITIONS.[1]

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INTRODUCTION.

Physical conditions during deposition—especially pressure and temperature—are of vital importance in determining the mineral association in ores formed by deposition from solutions. The object of this paper is to trace, in a general way, the relations of certain well-known mineral groupings to the physical conditions which there is reason to assume existed during their genesis. This method of approach must be adopted in the present state of our knowledge, for the more direct route—by experimentation—has as yet furnished too imperfect and scanty data to afford a basis for accurate conclusions.

It is well known that chemical reactions under ordinary surface conditions differ widely from those which prevail at great depths. Heat increases gradually below the surface until temperatures of potential rock fusion are attained and pressure undergoes a corresponding increase. The normal increment of temperature and pressure with depth can rarely, however, be separately considered, for intrusions of molten masses of rock may locally carry temperatures of abyssal depths closer to the surface

[1] Paper read before the Mexican meeting of the International Geological Congress, September 10, 1906.

and at the same time increase the pressure far above what is normal for any given depth. Wherever, therefore, in the following pages reference is made to deposits formed at great depth this reservation must be borne in mind.

In speaking of ore-deposits of varying depths the discussion always refers to the vertical distance from the points or levels under consideration to the surface of earth *at the time* of genesis, which involves, of course, the possibility of at least an approximate estimate of the amount of erosion that the deposit has suffered since its initial formation and of the geological epoch during which this formation took place.

It is significant that ores deposited in ancient eras often differ markedly from those of more recent times—and especially is this true of the ores of pre-Cambrian times; but these differences are largely accounted for by a deep erosion which has laid bare deposits formed at great depth. Moreover, since their genesis, the latter have been subject to many changes by rock-pressure and by the action of solutions.

Some years ago, in an article on the "Metasomatic Processes in Fissure Veins," an attempt was made by the writer to classify[1] the fissure veins from a metasomatic standpoint. It is clear that such a classification could be at best only tentative, and this was indeed directly stated in the paper, but it served as a framework in which the numerous observations and analyses, illustrating the changes of rocks in the immediate vicinity of ore-deposits could be temporarily and comprehensively arranged. A review of the new literature published since 1900 will not be attempted in this paper which is simply, in the main, a review of the primary precious metal deposits of the Cordilleran region as to their mineralogical and metasomatic features. Copper, lead, zinc and quicksilver ores are generally associated with these deposits and the values of these metals often exceed that of the precious metals.

Evidence of the genesis of these ores by hot waters has accumulated rapidly in the last few years. It is believed by many geologists that these hot waters were of magmatic origin. Pos-

[1] *Trans. Am. Inst. Min. Eng.*, 1900, Vol XXX., pp. 578–692.

sibly the zeal of the advocates of this view may carry them too far, and it is by no means denied that important ore deposits may be formed by sedimentary processes or by cold or hot circulating waters of atmospheric origin. No special attempt will be made in this place to advocate the deposition of ores by magmatic waters, although the probability of such an origin will be indicated as a corollary from the classification here outlined. Little emphasis will be laid upon the form of the deposits, as that is chiefly due to the various physical and chemical conditions of the rocks through which the hot solutions found their way.

To the mode of deposition in open cavities a few words may be devoted. It is universally conceded that open spaces of descission and solution may easily exist down to a depth of many thousands of feet below the surface. The hydrostatic pressure due to gravity will to some extent counteract the rock pressure and help to keep fissures open. But it is undeniable that in many abyssal ore deposits formed at very great depths below the surface veins are found which are undoubtedly due to the filling of rather large open cavities, which it is very difficult to conceive as having remained open under the tremendous pressure prevailing. An explanation has been sought in the force of crystallization; it has been supposed that this force would be great enough to force the walls apart. Among the advocates of this view are Professor Crosby of Boston Institute of Technology and Mr. Dunn of the Geological Survey of Victoria. The actual existence of such a force has been demonstrated by Messrs. Becker and Day.[2] Still, it seems scarcely possible to attribute such power to it as would be necessary to force deep-seated crevices apart to form room for the crystals, and another strong objection is that it would seem impossible that under these conditions comb structure and coarsely even-grained quartz could be produced.

Mr. L. C. Graton, in his recent studies of the gold and tin deposits of the Southern Appalachians,[1] has another explanation which is more likely to be the correct one. According to him,

[1] Bull. 293, U. S. Geol. Survey, p. 60.
[2] *Proc. Wash. Acad. Sci.*, Vol. 7, pp. 283–288.

the solutions which are of magmatic origin are under exceedingly heavy pressure in the deeper part of the crust, gradually diminishing as they ascend toward the surface, and this pressure, intimately related as it is to the tension of the intrusive magma from which the water is given off, would be abundantly sufficient to open the crevices to cavities and to allow undisturbed crystallization of the mineral substances dissolved in it. The magmatic solution would be essentially similar to magma intruding into dikes or to pegmatites crystallizing into hot granitic rocks; the pegmatites sometimes show most excellent comb structure, and their close structural relationship to certain classes of ore-bearing veins is one of the points substantiating the hypothesis explained above.

MINERAL-GROUPINGS CHARACTERISTIC OF ZONES OF DEPTH.

Few conceptions have caused greater advance in the study of the crystalline schists than that of gradually changing zones, each characterized by certain minerals stable under the conditions obtaining. What can be done in this direction is shown by the works of Van Hise, Becke and Grubenmann. The same principle is applicable to the ore deposits. The watery solutions ascending through the earth's crust are subject to constantly changing pressure, temperature and mass conditions; certain minerals stable, for instance, under very high pressure and temperature, can no longer exist under conditions prevailing near the surface. By careful consideration of geological conditions it becomes possible, in most cases, to decide whether a given deposit has been formed at the surface, at moderate depths or at a very great distance below the surface.[1]

Certain minerals have then their "critical level" which they cannot leave without falling prey to decomposition, while certain other minerals have such a large interval of existence that they may be classed as "persistent minerals."[2]

Upon comparing the mineral records of ore deposits, formed

[1] W. Lindgren, "Ore Deposition and Deep Mining," Economic Geology, Vol. I., No. 1.

[2] U. Grubenmann, "Die kristallinen Schiefer," Berlin, 1904, p. 55.

at various levels of the earth's crust, with the results obtained by students of general metamorphism, it very soon becomes apparent that the same laws do not apply to both cases, although there are many points of similarity. Attention was called to this interesting fact in the writer's paper on the metasomatic processes in fissure veins, and increasing knowledge emphasizes the distinction. Neither the rules of Van Hise nor the three zones of Grubenmann will fit closely the case of the ore deposits. The reason for this is not difficult to find. In metamorphism one deals with small quantities of solutions, as a rule, free from large amounts of carbon dioxide and sulphide of hydrogen. The ore deposits, on the other hand, were formed by large quantities of waters rich in these gases, heavily charged with alkaline carbonates, and ordinarily of a high temperature. A large number of silicates, and other minerals, fairly stable under the influence of ordinary deep ground water, are incapable of existence in most vein forming solutions. Biotite, amphibole, soda-lime feldspars, often also chlorite and serpentine, as well as magnetite, are included among these. Under high pressure and temperature many of these minerals prove stable, however, and are even formed by metasomatic processes in the veins. In the contact metamorphic ore deposits, formed under very high pressure and temperature, a new set of minerals will develop, some of which are especially characteristic for these occurrences.

Phenomena of stress are in most cases excluded during the formation of ore deposits; static conditions and hydrostatic pressure prevail.

The mineral deposits described below occur almost without exception in or close to masses of igneous rocks. For the pegmatites and contact metamorphic deposits this is self-evident, both classes being associated with bodies of rocks intrusive into the crust at varying but generally great depths below the surface. For several classes of veins a similar relationship to intrusive rock masses has been proved. In typical examples the intrusive body—which may be a granular rock or a porphyry—is surrounded by an aureole of contact metamorphic deposits of lead and copper, but usually poor in the precious metals. Fissure

veins bearing gold and silver are either contained in the igneous rock itself or in its immediate surroundings.

The veins in the pre-Cambrian rocks have in many places in the United States been demonstrated to have a pre-Cambrian age. Many geological considerations indicate that these deposits have been formed at great depths below the surface, and here, too, as a rule, a relationship to intrusive rocks can be shown.

There is still another and large class of veins carrying gold and silver which cut through volcanic flows of Tertiary or later age. In these we are enabled to fix the level of deposition with greater accuracy, and often it can be demonstrated by geological or physiographical considerations that a given deposit was formed only a few hundred feet below the original surface of the lava flow.

Lastly the orifices and sinters of the hot springs so abundant in these volcanic regions may be examined and the minerals here formed may be compared to those of veins and other deposits known to be formed at much greater depths.

The ore deposits discussed in this paper may for the present purposes be divided as follows:

1. Ore-deposits consolidated from a molten magma.
2. Ore-deposits made by aqueo-igneous solutions.
3. Ore-deposits made by aqueous hot solutions
   - A. Of deep-seated origin.
     - a. Ore-deposits due to contact-metamorphism of sediments by intrusive igneous rocks.
     - b. Cassiterite veins.
     - c. Apatite veins.
     - d. Gold and silver bearing veins.
   - B. Formed at shallow depths.
   - C. Formed at the surface.

1. ORE DEPOSITS CONSOLIDATED FROM A MOLTEN MAGMA.

Characteristic Minerals.—Magnetite, ilmenite, chromite, pyrrhotite, chalcopyrite, pyrite(?), pentlandite; they contain copper, nickel and cobalt, but are very poor in gold and silver. Platinum is sometimes present. Accompanying gangue minerals are those of basic or acidic igneous rocks.

2. ORE DEPOSITS MADE BY AQUEO-IGNEOUS SOLUTIONS. PEGMATITE-DIKES.

Characteristic Minerals.—Magnetite, bornite, arsenopyrite, molybdenite, cassiterite, wolframite.

Accompanying Gangue Minerals.—Quartz, muscovite, alkali feldspars, tourmaline, apatite, fluorite, spodumene, more rarely hornblende, soda-lime feldspars, etc.

These deposits contain very little gold and silver and are very rarely economically important except for tin ore, and minerals of the rare metals. Metasomatic action of the solution on walls of crystalline rocks is usually slight, though tourmaline and cassiterite may develop in the surrounding, usually granitic, rock. Pegmatite formation evidently requires very high temperature and the conditions are decidedly deep seated. The solution has a tendency to take up substance from the wall rock which may become part of the pegmatite and crystallize as garnet, zoisite, andalusite, staurolite and feldspars.[1] Certain pegmatite dikes in Boulder County, Colorado, occurring in hornblende gneiss show a lighter colored contact zone a couple of inches wide from which some of the dark silicates appear to have been absorbed. The pegmatites are not often found outside of their igneous mother rocks, but any metasomatic action on the wall rock is likely to be in the line of contact metamorphism. Pegmatite veins may gradually change into quartz veins, but no transitions have been satisfactorily shown to exist between these and the gold bearing fissure veins. At many contacts of intrusive rocks not characterized by pegmatites, quartz veinlets abound and often carry crystallized specularite. But where these veinlets cut feldspathic rocks like granite, no sericitization such as is the result of the action of hot waters at higher levels is observed.

[1] Weinschenk, Grundzüge der Gesteinskunde Freiburg i. B. 1902, p. 113.

3. ORE DEPOSITS MADE BY AQUEOUS SOLUTIONS.

A. OF DEEP SEATED ORIGIN.

(*a*) ORE DEPOSITS DUE TO CONTACT METAMORPHISM OF SEDIMENTS BY INTRUSIVE IGNEOUS ROCKS.

Characteristic Ore Minerals.—Magnetite, specularite, pyrite, pyrrhotite, bornite, chalcopyrite, zinc blende, galena, molybdenite. (Complicated sulpho salts, antimonides, tellurides, etc., are absent.)

Gangue Minerals.—Andradite- and grossularite-garnet, epidote, pyroxene, wollastonite, ilvaite, actinolite, spinell, diopside, calcite, quartz, scapolite, apatite and tourmaline. Biotite and muscovite, though occurring in contact metamorphic argillaceous rocks, are not common in the ore deposits. These deposits, which are almost exclusively of metasomatic origin, are apparently caused by replacement of calcareous rocks by very hot solutions given off by the cooling magma. These solutions were probably above the critical temperature and thus really in gaseous condition.

The deposition is, as a rule, confined to rocks on which the solutions exerted a strong chemical action.

The majority of contact metamorphic deposits are poor in gold and silver.

(*b*) CASSITERITE VEINS.

Characteristic Minerals.—Cassiterite, pyrite, arsenopyrite, specularite, quartz, tourmaline, topaz, lepidolite, muscovite, apatite, fluorite, and wolframite; calcite and siderite are not abundant.

The metasomatic processes along the veins are intense and result in the conversion of granites, crystalline schists and slates into often coarsely crystallized quartz, tourmaline or quartz-topaz-muscovite rocks.

The metasomatic action on limestone and clay slates is not known.

Feldspars and dark silicates are not stable but are replaced by the minerals mentioned; quartz is recrystallized. The changes in chemical composition are not extensive, as far as known, and no great concentration of potassium, so frequent in other classes

of veins, is observed. Fluorine, boron and many of the rarer elements are introduced.

The occurrence is as veins in and around intrusive masses of normal granite rich in soda. High pressure and temperature are probably necessary for the genesis of these veins, which are poor in gold and silver.

(*c*) APATITE VEINS.

Characteristic Minerals.—Apatite and other phosphates, scapolite, diopside, hornblende, biotite, specularite and pyrrhotite. Strong metasomatic action on the country rock is the rule and results in the development of scapolite, replacing soda-lime feldspar, and of malacolite replacing limestone. The introduction of chlorine or fluorine is characteristic, but the metasomatic processes are not known in their chemical details.

The occurrence is as veins following fissures or contraction joints in or about basic intrusives. High pressure and temperature are probably necessary for the genesis of these veins, which are poor in gold and silver.

(*d*) GOLD AND SILVER BEARING VEINS.

The deep seated veins containing gold and silver, with which are usually associated other metals in varying amounts, form a most important class, to which the larger proportion of the world's production of gold, and much of its silver, is due. They constitute a series with gradually changing characteristics, impossible to separate in sharply defined subdivisions.

The first group to be discussed is found in pre-Cambrian formations in various parts of the world and has lately been studied by Mr. Graton and myself in the southern Appalachians[1] and New Mexico.[2] All geological indications point to their formation at great depths under very heavy pressure and at high temperature. They are not entirely confined to these oldest formations, but also appear at places in more recent rocks wherever igneous intrusions have created the necessary special conditions of temperature and pressure.

[1] Bull. 293 U. S. Geol. Surv.
[2] Bull. 285 U. S. Geol. Surv.

Characteristic minerals are gold, pyrite, pyrrhotite, galena, zinc blende, magnetite, specularite, ilmenite, quartz, biotite, tourmaline, garnet (pyrope), hornblende, chlorite, apatite, spinell and epidote. Calcite is also present in small amounts. The replacement of the country rock is usually strongly marked; amphibolites and micaceous schist are replaced by tourmaline, garnet, a green biotite and epidote. The presence of apatite, magnetite and ilmenite is noteworthy. Soda-lime feldspars are unstable under the influence of the vein forming solutions and alkali-feldspars do not form, as a rule. There are no data as to the changes effected in limestone or argillaceous rocks, as the veins have not been observed in such surroundings.

The veins occur in or close to granite intrusive in schist.

In certain veins of this group sericite forms together with biotite and transitions obtain to the most common type of gold and silver veins, namely, the sericitic and calcitic type, which is so abundantly represented throughout the Cordilleran region in the vicinity of deep seated intrusions in rocks ranging in age from pre-Cambrian to Cretaceous. Though usually appearing as fissure veins, the deposits very often assume an irregular or bedded form wherever the containing rocks are easily soluble. Pressure and temperature must have been moderately high and the depth below the surface several thousand feet, as a minimum. All of these veins have been exposed by deep erosion and their epoch of formation can, in most cases, be shown to have closely followed the particular intrusion with which they are associated.

The principal minerals are: Gold, pyrite, chalcopyrite, arsenopyrite, galena, zinc blende, molybdenite, tellurides, tetrahedrite, often the mercurial variety; more rarely pyrrhotite and cinnabar. As gangue minerals appear quartz, calcite, dolomite and siderite, sericite, sometimes chlorite, barite and fluorite. The carbonates increase in quantity compared to the previously described class of veins. Absent or very rare are magnetite, specularite, hornblende, garnet, epidote, tourmaline.

A fairly thorough examination of the metasomatic conditions

of this class of veins has been made. In ordinary igneous rocks—acidic, basic or intermediate—almost all of the rock forming minerals are unstable under the influence of vein forming solutions of this kind. The list of unstable minerals comprises, among others, orthoclase, microcline, soda-lime feldspars, nepheline, amphiboles, pyroxenes, epidote, magnetite, ilmenite and titanite. Chlorite is, as a rule, ultimately decomposed, although somewhat away from the veins the first step of alteration by the solutions, here robbed of most of their active constituents, consists in a chloritization. In a few veins chlorite is capable of recrystallization with quartz. Quartz is on the whole stable but under the influence of solutions heavily charged with carbon dioxide a replacement and re-deposition of quartz by calcite, dolomite or siderite occurs. The two processes of carbonatization and sericitization prevail, and almost all of the original minerals are subject to them. Either one may quantitatively prevail according to the local composition of the solution. Carbonatization turns all or a large part of the iron, manganese, magnesia and lime of the rock into carbonates. Complete sericitization transforms the rock into a mixture of felted sericite and quartz and is usually accompanied by a removal of the iron and earthy bases, due to lack of carbon dioxide to fix them.

Titanite is altered to rutile and calcite; magnetite often to siderite; ilmenite to rutile and siderite. The only feldspar which approaches stability is albite. In rocks very rich in albite, like the amphibolites of California and Western Australia, only a smaller amount of sericite forms; the albite is dissolved and redeposited with quartz and carbonates either as filling or as product of replacement. Apatite appears stable but is not formed as an original vein mineral as is the case in the more deep-seated deposits. Pyrite replaces, in varying quantities, almost all of the rock forming minerals, but especially those rich in iron. Gold and most of the heavy metals penetrate the country rock only with difficulty and are deposited in the open spaces, if such are available. Silicification of the wall rock is a rather local and exceptional mode of alteration, as ordinarily the wall rock acts

as a semi-permeable membrane which does not admit the colloid solution of silica, while gases and salt solutions may easily permeate it. When silicification takes place it is usually due to mass action of surrounding shattered or porous siliceous rocks.

Clay slates consisting of quartz and sericite are very little affected by the vein forming solutions, but in shattered rocks of this kind a silicification often takes place. The same is often true of sandstones. In both pyrite is apt to form in abundance. Clay shales consisting of quartz, feldspar débris, glauconite and kaolin are a little more affected and often suffer carbonatization, sericitization and pyritization.

The effect on calcareous rocks is of particular interest, and very different from the processes just described. In some veins which are very closely related to intrusive bodies, such as the pyritic veins of Clifton, Arizona, it has been found that the impure limestone adjacent to the veins alters to tremolite or diopside with which are associated pyrite, magnetite and some epidote. The same vein solutions sericitize the monzonite porphyry of the district.[1]

A similar alteration has been observed by Lotti[2] along the copper, lead and zinc veins of Massa Marittima in Tuscany, which also contain a little gold and silver. They are more or less irregular fissure veins and replacement deposits carrying quartz as principal gangue. The Permian, Jurassic or Eocene limestones are in places near or in the veins converted to epidote, pyroxene and garnet rocks. Hot waters containing boron have been found in these veins, which are about six kilometers distant from a mass of tertiary, intrusive granite.

But in by far the majority of cases the pressure and temperature do not appear to reach the requisite point for the metasomatic development of these minerals. Ordinarily the limestones are simply silicified to fine grained jaspery rocks, or trans-

[1] W. Lindgren, "The Copper Deposits of the Clifton-Morenci District," Professional paper No. 43, U. S. Geol. Survey, p. 171.

[2] "Descrizione geologie-mineraria dei dintorni di massa Maritima," *Memorie della Carta geologica*, Bd. VII., Roma, Tipographia Nazionale 189. Also K. Ermisch, *Zeitschrift für prakt. Geol.*, Bd. XIII., 1905, pp. 206–242.

formed into dolomite. Calcareous rocks are easily penetrated by solutions of heavy metals, and hence the metasomatic development of pyrite, zinc blende, galena and chalcopyrite in them is extensive and important.

B. ORE DEPOSITS FORMED AT SHALLOW DEPTHS.

In the Cordilleran regions, as well as elsewhere in the world, veins containing gold with much silver, and, more subordinately, lead, zinc and copper, are found in flows of volcanic origin. In very many cases the geological conditions enable us to say with considerable certainty that these deposits have been formed at a relatively slight depth below the surface, say from a few hundred to four or five thousand feet below the actual surface of the ground, at the time of mineral deposition. Among these are, for instance, most of the veins of western Nevada, the San Juan region of Colorado, Cripple Creek and a great many ore deposits of Mexico. In the paper on Metasomatic Processes they have been described under the head of propylitic gold and silver veins, fluoritic gold tellurium veins, and in part also under sericitic and kaolinitic veins, and sericitic and calcitic veins.

These deposits are closely related to the sericitic and calcitic veins formed at greater depths which were described in the preceding paragraph. An unbroken line of transitions between them may in fact be found, but at the same time veins formed at slight depth possess certain characteristics of their own which will be briefly described. They have been referred to by Professor Vogt and others as "younger veins," in contrast to the "older veins" described in the preceding paragraph. A primary classification by age is, however, fully as much out of place here as it is in petrography. In descriptions of metallogenetic provinces age may, on the other hand, be suitably employed as a principal subdivision.

Gold and silver values prevail, though compared to the deep seated veins with quartz gangue there is more silver, and the native gold is, as a rule, present in much more finely divided form. Pyrite, galena, zinc blende, chalcopyrite, arsenopyrite

argentite and stibnite are the prevailing ore minerals, but more complex sulphides, sulphantimonites and sulpharsenites, such as ruby silver, stephanite, polybasite, etc., are more abundant than in deep seated veins. In part their presence may be due to a secondary enrichment by descending solutions, but opinions do not as yet agree regarding all of these occurrences. Of gangue minerals quartz prevails, but it is here often accompanied by chalcedony, opal or other forms of silica. Calcite and dolomite are moderately abundant in the vein filling, while siderite occurs more rarely. Barite and fluorite predominate locally. Magnetite and specularite, as well as the whole line of the silicates belonging to the greater depths of formation, are absent. Apatite is of very rare occurrence. On the whole, as may be expected near the surface, the filling of open cavities is a process of much importance.

The metasomatic processes differ, in character of course, in different country rocks. In igneous rocks of medium acidity a strong sericitization is very apt to take place immediately adjoining the vein with attendant concentration of potassium and leaching of lime, iron and magnesia. Pyritization is also of common occurrence. The solutions appear on the whole to have been poorer in carbon dioxide than those of the deep seated deposits and extensive carbonatization is therefore less common. On the other hand, the solutions have a tendency to spread from the veins through large area of adjoining rocks, probably owing to more extensive fissuring near the surface, and here, robbed of their most active ingredients, they produce the so-called "propylitization," which consists in the development of chlorite and epidote, as well as pyrite, from the dark silicates, and in the eventual degeneration of the feldspars into quartz, chlorite and epidote.

In very basic rocks this propylitization may proceed closely up to the veins, but as stated above, sericitization is likely to take its place. Complete silicification of the wall rock is more common in these deposits than elsewhere. In large altered areas irregular masses of completely silicified rocks are often met with.

These products of replacement are usually dark grey or brown and fine grained, flinty or cherty rocks. Siliceous rocks like rhyolite are especially subject to this irregular silicification.

One interesting feature is the very common development of adularia in the quartz filling as well as in the metasomatic products. The soda lime feldspars and the ordinary orthoclase or microcline, which contains more or less soda, is dissolved and redeposited as soda-free adularia. This process may proceed side by side with sericitization and the result in both cases is a concentration of and enrichment by potassium, while sodium is carried away. The formation of adularia evidently proceeds close up to the surface at temperatures which can but little exceed + 100° and under pressure of only a few atmospheres.

In calcareous rocks the products of replacement along these veins are usually fine grained quartz or chalcedonic jaspers and cherts.

The majority of cinnabar deposits—whether in veins or irregular masses—are also formed at no great depth below the surface. This does not imply that mercury is only precipitated near the surface, as advocated by some, for many of the ore deposits of the deeper zones contain this metal, occasionally as cinnabar, but more frequently as mercurial tetrahedrite or as telluride of mercury (kalgoorlite). The principal ore minerals of cinnabar deposits are, besides that substance, marcasite, pyrite, stibnite, all minerals susceptible of formation at slight depths. The metasomatic action on serpentine and other basic rocks consists in carbonatization (dolomitization) and silicification, opal and chalcedony being especially abundantly formed.

C. MINERAL DEPOSITS FORMED AT THE SURFACE BY HOT WATERS.

Mineral deposits may be formed at the very surface by hot springs, but they are then rarely of economic importance. A great number of minerals may result by direct deposition or by metasomatic action. All of the earthy carbonates contained in the water are here deposited at once, as sinter; the silica also as opal or chalcedony. The ordinary spring deposits thus consist

of a mixture of carbonate and chalcedonic or hydrous silica. Calcite, fluorite, barite, celestite and many other gangue minerals may also develop in crystallized form. Of ore minerals stibnite, pyrite, marcasite and cinnabar are known in crystallized form, and many other sulphides have been detected chemically in the deposits. Zeolites, such as chabazite, mesotype, stilbite and apophyllite are sometimes observed as products of rock alteration by mineral waters at the surface. Some sericitization of feldspathic rocks also takes place.

In most cases surface water containing atmospheric oxygen has acted on the sinters deposited at the surface or on the upper part of the veins. A complete change in the character of the deposits is effected by it. While under the influence of hot ascending waters practically no minerals rich in water form, and even zeolites are almost unknown, here, on the contrary, highly hydrated minerals are the rule. Limonite and the whole series of hydrous oxides, carbonates and sulphates of the heavy metals prevail among the ore minerals and kaolin, allophane and chloropal among the gangue minerals.

Kaolin has not been mentioned among the gangue minerals of any class of deposits except those formed or occurring under oxidizing influence, although the writer is well aware of the very general opinion to the contrary, and although in the paper on Metasomatic Processes referred to above he has himself formerly considered it as characteristic of certain classes of veins.

The hydrothermal origin of large bodies of kaolin has been urged in several recent papers,[1] by demonstrating the improbability of the formation of the mineral on a great scale by ordinary weathering and by indicating its connection with mineral deposits. Conceding this, it is nevertheless believed that kaolin is rarely formed by alkaline hot water at any considerable depth below the surface. Instances are multiplying (the occurrences at Cripple Creek among them) in which it can be shown that the kaolin of the upper levels exposed to oxidation changes into sericitic products in depth and that it is easily and abundantly formed

[1] O. Stutzer, *Zeitschrift für prakt. Geologie*, XIII., pp. 333–336, 1905.

by the action of solutions containing free sulphuric acid on sericitized metasomatic rocks and also, though less easily, on ordinary feldspathic rocks.

CONCLUSIONS.

The review given above indicates an almost unbroken series of deposits in which, in successively higher or cooler zones, the mineral combinations gradually change from those of pegmatitic and contact metamorphic conditions to those known to obtain at points where hot springs issue at the surface.

The contact metamorphic deposits have recently been connected with those of the lower vein zones by the discovery that some of the latter contain silicates and other minerals supposed to be characteristic of the former. Under heavy pressure minerals of small molecular volume tend to form from solutions, and naturally this tendency would be most strongly indicated in those ore deposits which are contained in calcareous rocks. At the highest temperatures and pressures obtaining the solutions do not readily attack the feldspar and dark silicates of surrounding crystalline silicate rocks, although some of the "agents mineralisateurs" may pentrate them and deposit minerals like tourmaline and topaz. This seems to be the chief and not yet thoroughly understood difference between contact metamorphic deposits and even the lowest vein zones in which the feldspars are unstable and are at once attacked under formation of various minerals. The ilmenite, spinell, amphibole, pyroxene, scapolite and biotite of the lowest vein zones are missed in the upper zones in which sericitization and carbonatization are the prevailing rules. The behavior of epidote is peculiar in that it is characteristic of the contact metamorphic deposits and the lowest vein zones, while it is absent in middle depths, only to appear again in some veins near the surface.

The general character of the solutions as we know them from the deposits at middle and upper vein zones is unquestionably alkaline, *i. e.*, they contained the alkaline carbonates as one of their principal constituents. There seems to be no evidence at all of the presence of such reagents as free sulphuric, hydrochloric, or hydrofluoric acid. At high temperature and pressure the

behavior of the solutions changes in a marvellous degree, but in view of the scarcity of experimental data it is hardly profitable as yet to discuss their constitution and mode of action.

It is not to be assumed that the solutions which formed the mineral deposits always had the same general composition. Within certain limits they doubtless varied greatly. While there are numerous analogies which tie together the pegmatites and the cassiterite veins as both characteristic of acidic intrusion of normal granite, there seems to be no such evident connection between pegmatite dikes and gold bearing veins. On the contrary, it appears that the intrusive granular and porphyritic rocks with which most of the auriferous veins are connected are remarkably deficient in pegmatitic dikes.

One of the most striking facts in the ore deposits here discussed is the scarcity of minerals containing much water, such as kaolin and zeolites. Even in upper vein zones with water present in large volumes, minerals like adularia or sericite will form instead of strongly hydrated forms.

The following incomplete lists indicate in a general way the ranges of the principal minerals of ore deposits:

PERSISTENT MINERALS.

(Ranging from Contact Metamorphic or Igneous Conditions up to Surface.)

Pyrite	Persistent from igneous conditions up to near surface.
Chalcopyrite	Persistent from igneous conditions up to near surface.
Bornite	Persistent from pegmatitic and contact metamorphic conditions to near surface. Rare in veins of middle depths.
Arsenopyrite	Persistent from pegmatitic or contact metamorphic conditions up to near surface.
Galena	Persistent from contact metamorphic conditions up to near surface.
Zinc blende	Persistent from contact metamorphic conditions up to near surface.
Molybdenite	Persistent from pegmatitic and contact metamorphic conditions up to near surface.
Gold	Persistent from igneous and contact metamorphic conditions to surface.
Quartz	Persistent from igneous conditions to near surface where chalcedony and opal takes its place. Locally attacked and replaced by sericite, carbonate and ores.
Calcite	Persistent from contact metamorphic conditions to surface.

FLUORITE	Persistent from igneous through contact metamorphic and pegmatitic conditions to surface.
RUTILE	Persistent from igneous conditions to near surface.
EPIDOTE	Persistent from contact metamorphic conditions to surface; except: unstable in all vein deposits of middle depths and in many of the upper zone, alsq unstable under igneous and pegmatitic conditions.
MUSCOVITE (with SERICITE)	Persistent from igneous conditions to near surface. Developed as sericite in deposits of middle and upper zone.

MINERALS OF CONTACT METAMORPHIC DEPOSITS.

PYRRHOTITE,
ILMENITE,
MAGNETITE,
SPECULARITE,
SPINELL,
CORUNDUM,
CASSITERITE,
ANORTHITE,
ALBITE,
GARNET,
ANDALUSITE,
STAUROLITE,
ILVAITE,
TREMOLITE,
DIOPSIDE,
EPIDOTE,
VESUVIANITE,
WOLLASTONITE,
TITANITE (only in contact metamorphic limestones),
SCAPOLITE,
TOÜRMALINE,
TOPAZ,
APATITE.

MINERALS OF DEEPER VEIN ZONES.

PYRRHOTITE,
TELLURIDES,
ILMENITE,
MAGNETITE,
SPECULARITE,
SPINELL,
CASSITERITE,
ALBITE,
HORNBLENDE and TREMOLITE,
DIOPSIDE,
GARNET,
BIOTITE,
TOURMALINE,
TOPAZ,
SCAPOLITE,
APATITE,
BARITE.
DOLOMITE,
SIDERITE.

MINERALS OF MIDDLE AND UPPER VEIN ZONES.

CINNABAR,
MARCASITE,
MARCASITE,
TELLURIDES,
TETRAHEDRITE,
TENNANTITE,
PYRARGYRITE,
STEPHANITE,
POLYBASITE,
ARGENTITE,
CHLORITE,
EPIDOTE (see above),
ALBITE,
ADULARIA,
BARITE.
CELESTITE,
DOLOMITE,
SIDERITE.

MINERALS UNSTABLE IN ALL VEIN ZONES.

Anorthite,
Soda-lime feldspars,
Orthoclase,
Titanite,
Zeolites (unstable with few exceptions).

MINERALS FORMED IN LOWER GROUNDWATER ZONE OF ORE-DEPOSITS (ZONE OF SECONDARY SULPHIDE ENRICHMENT).

Quartz,	Bornite,[1]
Chalcedony,	Covellite,[1]
Opal,	Chalcocite,
Kaolin,	Argentite,
Gold,	Pyrargyrite,
Silver,	Stephanite,
Pyrite,[1]	Polybasite,
Galena,[1]	Other complex Sulpharsenites and Sulphantimonites.
Chalcopyrite,[1]	

MINERALS FORMED IN OXIDIZING GROUNDWATER ZONES OF ORE-DEPOSITS.

Chalcedony,	Sulphates,	of Heavy Metals,
Opal,	Carbonates,	
Kaolin,	Phosphates,	
Limonite,	Arsenates,	
Pyrolusite,	Chlorides,	
Hematite,[1]	Gold,	
Cuprite,[2]	Copper.[2]	

The following additional table will be of some service in representing more graphically the occurrence of minerals in ore deposits under varying conditions:

[1] Stable under certain conditions.
[2] Transition form.

MINERALS FORMED IN ORE-DEPOSITS UNDER VARYING CONDITIONS.

Mineral.	Igneous Condition.	Pegmatitic Conditions.	Contact Metamorphic Conditions.	Deeper Vein Zone.	Midd'e and Upper Vein Zone.	Lower Ground Water Zone. (Zone of Sulphide Enrichment.)	Upper (Oxidizing) Ground Water Zone.
Pyrite	+?	+?	+	+	+	+	
Chalcopyrite	+	+	+	+	+	+	
Bornite		+	+	+	+	+	
Arsenopyrite		+	+	+	+		
Galena			+	+	+	+	
Zincblende		+?	+	+	+		
Molybdenite		+	+	+	+		
Gold	+	+	+	+	+	+	+
Quartz	+	+	+	+	+	+?	
Calcite			+	+	+	+	
Fluorite	+	+	+	+	+		
Rutile	+	+	+	+	+		
Epidote			+	+			
Muscovite	+	+	+	+			
Sericite				+	+		
Pyrrhotite	+	+	+	+			
Ilmenite	+	+?	+	+			
Magnetite	+	+	+	+			
Specularite		+	+	+			+
Spinell	+	+	+	+			
Corundum	+	+	+				
Cassiterite	+	+	+	+			
Anorthite	+	+	+				
Albite	+	+	+	+			
Garnet	+	+	+	+			
Andalusite		+	+				
Staurolite				+			
Ilvaite				+			
Tremolite				+			
Hornblende	+	+	+	+			
Diopside	+	+	+	+			
Vesuvianite				+			
Wollastonite				+			
Titanite	+			+			
Scapolite		+		+			
Tourmaline	+	+	+	+			
Topaz	+	+	+	+			
Apatite	+	+	+	+			
Barite				+	+		
Dolomite			+?	+	+		
Siderite				+	+		
Cinnabar				+	+		
Marcasite					+		
Tetrahedrite				+	+		
Pyrargyrite					+	+	
Stephanite					+?	+	
Polybasite					+?	+	
Argentite					+	+	
Stibnite					+		
Tellurides				+	+		
Chlorite					+		
Adularia				+?	+		
Celestite					+		
Opal & Chalcedony					+	+	
Kaolin					+	+	+
Chalcocite				+?	+?	+	
Covellite						+	
Limonite							+
Pyrolusite							+
Cuprite							+
Copper					+		+
Silver						+	+
Cerargyrite							+
Carbonates of Pb, Cu Zn. Sulphates Silicates Arsenates Phosphates							+
Soda-lime feldspars	+	+	+				
Orthoclase	+	+	+				
Zeolites		+				+?	

DEPOSITS FORMED BY CONCENTRATION OF MINUTE QUANTITIES OF METALS DISSEMINATED IN ROCKS.

As stated in the introduction the above discussion by no means includes all ore deposits. It has purposely been limited in the main to those veins and other deposits of the Cordilleran region which yield almost the whole production of the West of gold, silver, copper, lead, zinc, and mercury, and to which a genesis by hot ascending waters is commonly attributed, however far the opinions may diverge concerning the origin of that water.

The following paragraphs are simply added to indicate some other lines along which metal deposition has been proceeding.

Many mineral deposits have doubtless been formed by concentration of minute quantities of metals contained in the surrounding rock. It is only intended to mention two classes of these deposits, both containing copper as the principal metal, but formed in different ways.

(*a*) *By Static Hydro-metamorphism.*—It is a well known fact that basic rocks like diabase, gabbro and some melaphyrs almost invariably contain an easily determinable percentage of copper with which may be associated smaller amounts of cobalt, nickel, silver and a few other metals. The ordinary forces of hydro-metamorphism are sometimes sufficient to concentrate these minute quantities into workable copper deposits. It is believed that the effect of this is shown in the Lake Superior region. The mineral association of chlorite and epidote, abundant zeolites and native copper, appears to show clearly enough that juvenile or other hydrothermal ascending waters are not responsible for these deposits.

(*b*) *Under Conditions of Stress.*—Many copper bearing rocks of the character just described have been transformed by the action of stress and metamorphism into chloritic or amphibolitic schists with local masses of pyritic copper ores. Under these conditions pyrite, chalcopyrite, pyrrhotite and magnetite are stable, as are quartz, muscovite, biotite, epidote, hornblende and albite, a combination which in the formation of deposits by thermal waters is only duplicated in contact metamorphism or in

the abyssal veins. There is evidence that under conditions of dynamic metamorphism this combination can persist at much lower temperatures than prevailed in the two classes of deposits mentioned. Many of the so-called pyritic deposits and fahlbands in the crystalline schists are apparently caused by a concentration of this kind, while others are wholly different and owe their origin to contact metamorphism and to replacement by thermal waters. The very small quantity of moisture contained in the rock seems to be sufficient for the transformations of dynamic metamorphism. Such conditions are very different from those created by strong currents of thermal waters, heavily charged with gases and dissolved salts.

SOME RELATIONS OF PALEOGEOGRAPHY TO ORE DEPOSITION IN THE MISSISSIPPI VALLEY.[1]

H. Foster Bain.

ORE DEPOSITS IN SEDIMENTARY ROCKS.

INTRODUCTION.

Recently much has been written concerning the relations of ore deposition to igneous rocks and to the processes of eruption and intrusion. The corresponding relations of certain classes of ores to sedimentary rocks and to sedimentation has been less discussed. Formerly this phase of ore genesis attracted more attention, and in the writing of Bischof, Groddeck, Hoefer, Phillips, Whitney, Chamberlin, Winslow and others, may be found much relating to the precipitation of metals from sea water and their later segregation into workable deposits.

In an interesting and valuable paper on igneous rocks in relation to the occurrence of ores, J. E. Spurr has considered briefly the distribution of metals in sedimentary rocks.[2] Among American writers few have emphasized more than Spurr the very intimate relations of ores to igneous rocks; for that reason what he says regarding the relations of sedimentary rocks and ores is of peculiar interest. It may be stated that Spurr's general views on ore deposits coincide most closely with those of J. H. L. Vogt among European writers.

Spurr notes that sediments are derived from igneous rocks and in the process great concentration takes place. Calcium becomes concentrated into limestone, silicon into sandstone, and commercially valuable deposits of salt, gypsum, phosphate of lime,

[1] Paper read at the Mexican meeting, Tenth International Geological Congress, September 10, 1906.

[2] J. E. Spurr, "A Consideration of Igneous Rocks and their Segregation and Differentiation as Related to the Occurrence of Ores," *Trans. Am. Inst. Min. Eng.*, Vol. 33, 1903, pp. 288–340.

borax and other minerals are formed. The metals must at the same time be dissolved. In the case of iron, bogs, greensands and ferruginous shales are formed, which with slight further concentration produce workable deposits. Manganese is also concentrated. Gold, platinum, diamonds, tin ore, monazite, garnet, etc., are gathered in places and afford samples of the enormous efficiency of surface agencies. These are, however, all either common elements, or are relatively insoluble. Concerning silver, copper, lead, arsenic, antimony, etc., metals which are at once somewhat rare and somewhat soluble, less satisfactory conclusions may be drawn. Upon destruction of igneous rocks the contained metals must go largely into solution. Some of the water passes underground, and the material is reprecipitated, but much passes into lakes and the ocean. Since it is impossible to assume that these metals have been accumulating in the ocean from the beginning, they must have been precipitated from it. Of this there is indeed independent evidence. The sedimentary rocks, however, seem to contain, on the average, less of these metals than equivalent amounts of igneous rocks, so that it follows that precipitation must have been irregular and original concentrations must have resulted.

Spurr thus deductively reaches the conclusion that sedimentation must lead to the presence of metallic minerals in the sedimentary rocks, and that there must be areas in which these exist in relatively concentrated form. In order to avoid confusion it will be useful to speak of the latter as metalliferous concentrations, meaning thereby bodies of rock which contain more than the normal amount of any metallic constituent. The term ore deposit may be reserved for those concentrations in which the abnormal amount of metal present is sufficient to permit of the working of the deposit.

Much study has been devoted to the processes by which metalliferous concentrations are reconcentrated to form ore deposits, and for the region in question, among others, C. R. Van Hise has admirably summarized the processes and agencies.[1] Less

[1] "Some Principles Controlling the Deposition of Ores," *Trans. Am. Inst. Min. Eng.*, Vol. 30, pp. 27–177.

is known regarding the formation of the parent metalliferous concentrations, particularly in sedimentary rocks. In igneous rocks the processes of differentiation have been appealed to and carefully investigated. In case of deposits in sedimentary rocks it is not even conceded by all that there has been a preceding metalliferous concentration; various authors having held that the whole process might be secondary to the formation of the rocks in which the ore deposits occur. It is not intended here to deny that such a concentration is possible and may perhaps have occurred. It is, however, held that in general, ore deposits formed in sedimentary rocks without direct contributions from igneous rocks or the aid of heat and other agencies incident to their intrusion or eruption, come from parent, primary, metalliferous concentrations. It is proposed here to discuss the processes of formation of certain of these parent concentrations.

It will be convenient to exclude at once all placers and mechanical deposits, since they form a class by themselves; a class, moreover, whose origin is fairly well understood. Taking into account only those deposits which occur as the result of some chemical or bio-chemical process, and for convenience excluding the rarer elements, we have ores of iron, manganese, copper, lead, zinc, gold, silver, arsenic and antimony.

The four last named are rarely found in commercial quantities in unaltered sedimentary rocks. Iron, manganese, lead, zinc and copper all occur, and large and important deposits are known, which owe nothing directly to igneous forces. Iron and manganese are especially characteristic of such rocks and have been much studied. It is well known that iron in the form of black band ores in the Coal Measures, and as red hematite in the Clinton formation, occurs in workable deposits which have been little if at all concentrated since their original precipitation from sea water. Other iron ores such as the great deposits of the Lake Superior region have resulted from the reconcentration of primary metalliferous concentrations; cherty-iron-carbonates, greensands, etc. Manganese, as from its close association with iron might be expected, offers similar excellent examples.

The conditions under which compounds of lead, zinc and copper may be deposited from the sea are not well understood, but there is sufficient evidence for believing these metals are so precipitated, and there are horizons and districts which seem to have been the locus of such deposition.

In certain important particulars the Mississippi Valley offers a unique opportunity to study the relations of sedimentation to ore deposition. In the last decade it has been the good fortune of the writer to see something of the ore deposits of this region in connection with official work for the Iowa, Illinois and United States Geological Surveys, and the following conclusions are based upon these observations. In order not to trespass too long, attention will be directed here especially to the lead and zinc deposits.

THE MISSISSIPPI VALLEY.

Rocks of the Mississippi Valley.—The valley north of the Gulf Plains and south of the Lake Superior region is a great area of flat-lying, unaltered Paleozoic sediments, which to the west pass under the Red Beds and Cretaceous sandstones of the Great Plains. To the east the valley is bounded by the Appalachian Mountains, which are made up of rocks of the same age, but are structurally independent; a difference which dates from the Permian orographic revolution. The valley itself is practically free from deformation, dips being measurable in meters per kilometer rather than in degrees. The prevailing rocks are dolomites, limestones, shales and sandstones. Coarse sediments are almost entirely absent. The beds were laid down under shallow water conditions with concomitant leaching of the low-lying, pre-Cambrian, crystalline rocks surrounding the area. The region is practically free from later intrusive rocks, a scant dozen dikes being known. Throughout geologic history the valley has acted as a unit, and since the Paleozoic it has been subjected to prolonged erosion at low altitudes. Neglecting the Ouachita Mountains of southwestern Arkansas, which belong structurally with the Appalachians, the only important deformation areas are, the Ozark uplift, an extensive, low, broad, ellip-

tical dome, whose present elevation represents a slight warping of the Cretaceous peneplain, and the Wisconsin uplift, a similar warped area. In both instances the uplifts include pre-Cambrian rocks, which seem to have formed islands through much of the Paleozoic, and to have furnished the bulk of the material now represented in the flanking sediments. The old lands to the east, south and possibly to the west, also contributed. While there were frequent shiftings of the shore line, conditions seem to have remained much the same from the Middle Cambrian to the Permian, the area being occupied by a shallow semi-enclosed marine basin, surrounded by low plains of crystalline rocks which contributed largely by solution and secondarily by corrosion to the slowly forming sediments.

Ores of the Mississippi Valley.—The importance of this region as an ore producing district is not always properly appreciated. Neglecting altogether the Lake Superior district, the Ouachita Mountains and the early iron output from the Coal Measures, there is still a recorded production of nearly $300,000,000 worth of metallic ores. The most important single item is lead ore, which to the close of 1904 amounted in value to approximately $168,600,000. Zinc, amounting to $93,500,000 comes next, followed by iron, $31,000,000, in which is included only the iron ore of Missouri. The Arkansas manganese mines have yielded a trifle less than $500,000, while the recorded copper production of Missouri and Wisconsin approximate $400,000 in value. If the record were to be made complete something would need to be allowed for the nickel and cobalt from Mine La Motte in Missouri, a little for silver from the Einstein Mine in the pre-Cambrian rocks of the same state, a trifle for gold from placers in the drift of Indiana, and considerable for scattered iron deposits in Iowa, Illinois, Indiana, and other states. It is evident that these totals are important and that the valley deserves to rank among the major mining regions of the world.

Production has centered mainly in three areas: (*a*) Southeastern Missouri, which has yielded in lead, iron and copper nearly $120,000,000; (*b*) southwestern Missouri and adjacent

portions of Kansas and Indian Territory, which have yielded in zinc and lead about $118,000,000; (*c*) southwestern Wisconsin, including portions of Illinois and Iowa, and having a recorded production of lead, zinc and copper of approximately $60,000,000. Mining in all of these districts is still active despite the fact that operations began in 1719.

There are two classes of ore deposits in the Mississippi Valley. The first and more important includes the principal deposits of lead, zinc, copper, iron and manganese. These are believed to have resulted from reconcentration of primary metalliferous concentrations, developed in situ, or nearly in situ during periods of Paleozoic deposition. This class includes the bulk of the ores of the Ozark region and also those found in Wisconsin. The second and less important group includes a few deposits formed by exceptional agencies and under unusual conditions, and deriving their material apparently from small quantities of widely disseminated metal concentrated by powerful solvents or from deeper or now buried rocks. This class is represented in the zinc-lead fluorspar deposits of southern Illinois and western Kentucky, also possibly in the similar deposits of central Kentucky.

THE WISCONSIN DISTRICT.

The Ore Deposits.—The influences of paleogeography in the formation of metalliferous concentrations can be seen best perhaps in the case of the Upper Mississippi Valley or Wisconsin lead and zinc district. The deposits here occur on the southwest flank of the Wisconsin uplift. No corresponding deposits are known in eastern Wisconsin, though the formations are similar and the opportunities for secondary concentration equally favorable. The district is within a driftless area, surrounded by glacial drift. The ores occur in the Platteville limestone and the Galena dolomite; formations of mid-Ordovician age, corresponding roughly to the Trenton of eastern United States. The mines are not deep, 30 to 60 meters, and the ores have nowhere been mined far below water level. In form the ore bodies are peculiar. Above water level the deposits occupy small crevices,

for which J. D. Whitney coined the term "gash veins."[1] In these crevices they form horizontal ore shoots or runs, known locally as "openings." Below, the vertical crevices give way to horizontal flat openings between bedding planes, connected by pitching joints. These are known as "pitches and flats." In the crevices, above water level, galena and zinc carbonate are the common ores. In the pitches and flats the ore consists of blende, galena and marcasite, intimately intergrown or in alternate layers or crusts.

The mines are distributed irregularly through the district in clusters between which is barren ground where the country rock is the same and conditions for concentration seem equally good. They occur within the limit of very flat, shallow, irregular, structural basins which are believed to be essentially depositional and only very slightly intensified by deformation. These basins have recently been the subject of much careful study, and a number of them have been mapped by Dr. U. S. Grant from the Geological and Natural History Surveys of Wisconsin.[2]

Origin.—With regard to the origin of these deposits there has been for many years practical agreement that they were derived by some form of lateral secretion from the surrounding rock. The only recent writer who has argued for their derivation from below is W. P. Jenny,[3] whose arguments are based mainly upon analogy and general principles. The deposits have been recently described in some detail by the writer in a general report upon the area.[4] From that report the following regarding the reasons for believing in primary metalliferous concentrations as one step in the formation of the ore deposits is abstracted.

For the original source of the metal it is doubtless necessary to look to the ancient crystalline rocks of the Lake Superior

[1] "Metallic Wealth of the United States," 1854, p. 48.

[2] Report on the Lead and Zinc Deposits of Wisconsin, with an Atlas of Detailed Maps. Wisconsin Geol. Nat. Hist. Survey, Bull. 14, 1906. 100 pages.

[3] "Lead and Zinc Deposits of the Mississippi Valley," *Trans. Am. Inst. Min. Eng.*, Vol. 22, 1894, pp. 171–225, 642–646.

[4] Zinc and Lead Deposits of the Upper Mississippi Valley. U. S. Geol. Surv., Bull. 294, in press.

region, which are known to carry both lead and zinc. That the immediate source was the surrounding dolomite is known, both by inference and direct test. Dr. J. B. Weems has shown that the country rock, even when apparently barren, contains small quantities of both metals.[1] No sufficiently accurate method of sampling has been devised to determine whether the metallic minerals were originally disseminated equally or unequally. In view of the changes of distribution incident to the later concentration of the ores, it is improbable that the matter can be settled in this manner. That the distribution was originally unequal, that in fact the present ore bodies are derived from parent primary metalliferous concentrations, may be affirmed with some assurance on the basis of indirect evidence. The present ore bodies are believed to have been formed mainly by the reduction of sulphates to sulphides as a result of the mingling of solutions and the reactions between ore-bearing solutions and the organic matter in the country rocks.

To a subordinate degree the sulphurization of carbonates has probably taken place. It seems altogether likely that the original precipitation of the materials from the sea water occurred through the same reactions. If this be true any original localization of material may have been due to: (*a*) Local abundance of the metals in solution; (*b*) local abundance of the organic reducing matter; (*c*) locally peculiar organic matter leading to particular efficiency in producing deposition.

Since lead and zinc are doubtless unequally distributed in the crystalline rocks to the north, it is entirely possible that the drainage reaching the Ordovician seas might have brought more of the metals in solution to certain portions of the coast than to others. The composition of river water varies greatly, and it is entirely possible that one or two streams, tributary to the sea in the present mining region, brought down unusual amounts of lead and zinc. This hypothesis is wholly unverifiable as far as present data goes. The only direct evidence favoring it is the fact that certain basins in which the ores now occur are sug-

[1] Iowa Geol. Surv., Vol. 10, 1900, p. 567.

gestive in shape of embayments at the mouths of streams, or drowned river valleys. The presence within them, and not generally elsewhere, of considerable amounts of mechanical sediment deposited during a general period of base leveling, is furthermore suggestive of nearness to rivers. The latter because of their long linear courses would show, in the bringing in of mechanical sediment, the effect of uplift at any point in a wide area.

It may, therefore, be noted that such slight evidence as is available confirms rather than opposes the notion that there were originally rich and lean patches of rock.

Whitney and Chamberlin have appealed to local abundance of organic matter for an explanation of the localization of the ores. Whitney evidently had in mind the organic matter due to the decay of animals such as form the ordinary fossils found in the rocks, though the agency of long branching sea weeds was also called into requisition.[1] The notion that this was the first appearance of abundant animal life and hence cause for the precipitation of metals from a "primeval ocean" has long since proved incorrect. It is furthermore a fact that the ore deposits within the district do not show that close relation to the more fossiliferous rock which the theory would seem to demand. It is also true that so far as these forms of life are concerned the Galena and other formations of this region seem equally fossiliferous entirely outside the ore-bearing area.

Chamberlin appealed to local abundance of fossils of the ordinary type of seaweeds and of fucoids.[2] He mapped the sea currents of the Ordovician in such a way as to show the possibility of the formation of a sargossa sea in the region, but did not deem the latter essential.[3] His most important suggestion was that the irregularities of the sea bottom would lead to the accumulation of the organic matter in the basins. These depressions were judged to be "more favorable to the life and growth of average marine species than the most exposed elevations of

[1] Geol. Illinois, Vol. 1, 1866, p. 199.
[2] Geol. of Wisconsin, Vol. 4, p. 536.
[3] *Op. cit.*, p. 533.

the sea bottom. But, however, that may be, it is altogether certain that the movable remains of dead organisms would be mainly accumulated in the depressions, and that all floating material would find lodgment there. So that the depressions of the original ocean bottom were the areas in which were concentrated the organic matter, to whose agency the removal of metalliferous solutions from the ocean is to be attributed."[1]

The importance of this observation arises from the fact that these original basins became later the locus of deformation and are the present "synclines" within which the ores are found. That this is a true cause can hardly be doubted, but it by no means follows that there were not other causes contributory if not actually coordinate in importance.

Organic matter is a loose general term covering a very large variety of compounds. These have markedly different efficiencies in the reduction of sulphides and in other reactions. Jenney[2] has devoted particular study to this matter and has calculated what he calls the "relative reducing power or duty" of equal weights of a considerable number of organic and inorganic compounds. In his table, hydrogen oxidized to water, is taken as a standard and given a value of 100.

A few of the more important values are given below:

RELATIVE REDUCING POWER.

Hydrogen, oxidized to H_2O	100.00
Marsh gas, CH_4, oxidized to $H_2CO_3 + H_2O$	50.00
Petroleum, $C_5H_{22} + 2$	43.36
Carbon, oxidized to CO_2	33.33
Native Humus Acid, $C_{46}H_{46}O_{25}$	18.04
Carbon, oxidized to CO	16.67
Sulphuretted hydrogen, H_2S, oxidized to H_2SO_4	23.53
Pyrite and Marcasite, FeS_2, oxidized to $Fe_2O_3 3H_2O$ and S to SO_3	12.50
Blende ZnS, oxidized to $ZnSO_4$	8.25
Carbon monoxide, CO, oxidized to CO_2	7.14
Galena, PbS, oxidized to $PbSO_4$	3.35

It is evident from this table that it is very material in what

[1] *Op. cit.*, p. 537.

[2] "The Chemistry of Ore Deposition," *Trans. Amer. Inst. Min. Eng.*, Vol. 33, 1903, pp. 445–498.

form the organic matter is present. The rate of decomposition is also important. If very slow, the amount of material available at any one time may be so small as not to produce an appreciable effect. If very fast, the whole of the material may be given off as a gas or light oil precipitating only the small amount of metal present at one time in the sea. If neither too fast nor too slow, the escaping gases and oils may arise through the sea and even through a considerable thickness of sediment, continuing indefinitely to precipitate such suitable metallic solutions as come within their sphere of contact.

In the Wisconsin district a probable source of such gas and oil exists in a bituminous shale, known locally as "oil rock" and found in irregular patches along the contact between the Platteville and Galena formations in which the ore occurs.

The material is a finely laminated brown to black shale. It is commonly of a dark chocolate color. When burned it gives off a distinctly petroleum odor, and it is from this that it is named. It has evidently suffered loss in bulk which has induced settling in the beds above. Chemically the material consists of impure limestone impregnated with organic matter. The latter amounts to as much as 40 per cent. by weight and is largely volatile. Leaching the material with ether gives a thick heavy oil, which contains an appreciable amount of sulphur. An examination by Mr. Rollin Chamberlain showed that the rock yielded 57.46 volumes of volatile matter when held at a red heat in a vacuum for two hours. A gas analysis of the material given off resulted as follows:

	Per Cent.
Hydrogen vapors	11.11
Heavy hydrocarbons	4.00
CH_4	35.98
H_2S	6.79
CO_2	18.12
CO	8.40
O	.26
H_2	13.18
N_2	2.21
	100.05

A microscopic examination of the shales by Mr. David White, showed that they consist largely, in places up to 90 per cent., of small flattened unicellular plant remains, probably algæ, bedded in a bituminous jelly. The presence of bacteria was detected, and the partial destruction of the plant cells is believed to have been due to their action. The pelagic or floating algæ are believed to have fallen in prolonged showers in quite protected areas where the water was presumably somewhat charged with tannic or humic solutions conducive to the early arrest of anaerobic bacterial decomposition. Possibly the bacterial action was arrested by its own products.

These buried plant remains, only partially decomposed and even now capable of giving off complex hydrocarbons of high reducing power, are believed to have determined the locus of the future ore bodies. That the material is even yet very efficient in the reduction of sulphates has been experimentally proved in the laboratory by F. F. Grout. After its burial, just so long as oil and gas resulting from its slow decomposition could make its way upward through the accumulating sediments, the overlying sea bottom afforded the maximum conditions favorable to the deposition of sulphides. In the process the oil rock itself necessarily decreased in bulk. That it has suffered loss of a large amount of its volatile matter is abundantly indicated. The small interbanded layers of limestone have been broken and brecciated, and in places the oil rock becomes almost a breccia in appearance with slickensided surfaces indicating movement of the particles against each other. Individual pieces of oil rock are bent and recurved, and the softer material has been squeezed in and around the harder fragments. The whole mass is ordinarily finely laminated like a shale or slate, and has every indication of having yielded to the vertical pressure of the overlying beds.

The amount of decrease in bulk which the rock has suffered cannot be determined absolutely. If it be assumed that the loss has been as great as that which has occurred in the formation of ordinary bituminous coal, a settling of two to fourteen feet of the overlying beds might reasonably be expected to have occurred.

This is more than enough to account for the flat open spaces which are found over the oil rock patches, and such settling seems eminently calculated to produce the peculiar pitching crevices in which the ore deposits occur and which circle the flats and lead down to the oil rock. The development of the fractures opened the way for the escape of more volatile matter, the further slumping of the rock and the consequent formation of more open spaces for the later concentration of ore. There is in these mines usually a perceptible sag between the pitches, which is interpreted as being in part the expression of pre-existing inequalities in the bottom and in part the unequal settling due to difference in thickness of the oil rock layers.

In these irregular patches of oil rock we have then, (1) a locally abundant supply of suitable reducing matter with a distribution concordant with the ore deposits, (2) a material peculiarly suitable to the reduction of sulphates and the sulphurization of carbonates; (3) a supply which was not only abundant when the beds were laid down, but which is even yet highly efficient; (4) a material which is both qualitatively and quantitatively adequate to account for the most puzzling structural features of the deposits. These facts would seem to warrant the conclusion that the original distribution of the metals in the Platteville and the Galena was irregular and that the present ore deposits are found within the areas which were originally richer.

OTHER DISTRICTS.

The remaining districts of the Mississippi Valley have not yet been studied in such detail, and it is accordingly impossible to speak as definitely regarding them. In some it is believed that the deposits are epigenetic and that their localization was determined by such phenomena as the position of suitable fractures for the circulation of underground waters. This is the explanation which has been offered for the ores of the Missouri-Kansas district.[1] In this case the parent metalliferous concentration is

[1] Bain, H. F., "Preliminary Report on the Lead and Zinc Deposits of the Ozark Region." U. S. Geol. Surv., 22d Ann. Rept., Part 2, pp. 27–227.

assumed to be in the Cambrian or Ordovician rocks of the central part of the Ozark uplift.

In southeastern Missouri there are such striking differences in composition and form of ore body between the lead ores of the Cambrian (Bonne Terre) and the zinc-lead ores of the Ordovician (Potosi), that it hardly can be doubted that the two are referable to quite different sources or conditions of deposition. It is possible that the Bonne Terre ore was an epigenetic, while the Potosi ores show many striking analogies to those of Wisconsin. The ores of central Missouri, and some, at least, of those of north Arkansas, show also great similarity to the Wisconsin ores and suggest a similar history.

In all these districts the ores are either now in Ordovician rocks or are believed to have been derived from primary metalliferous concentrations in rocks of that age. In all districts the Ordovician rocks are similar, being shallow water dolomites. This is true also of the deposits found in southwestern Virginia and eastern Tennessee, which before the Permian orographic revolution formed a portion of the Mississippi valley geologic province.

CONDITION OF ACCUMULATION.

So far as can now be determined the parent metalliferous concentrations follow along old shore lines where in shallow water, free from much mechanical sediment, the conditions which promoted the alteration of limestone to dolomite as fast as formed, also favored the concentration and precipitation of the metallic sulphides. In certain local areas where conditions were most favorable exceptional quantities of the materials were precipitated, but apparently throughout the Paleozoic, conditions were generally sufficiently favorable to allow of small quantities being thrown down.

The conditions which permitted the formation of lead and zinc concentrations seem also to have allowed the deposition of iron, manganese and copper. These ores tend to follow certain stratigraphic horizons and in the case of copper at least,[1] shallow, shel-

[1] H. F. Bain and E. O. Ulrich, "The Copper Deposits of Missouri," U. S. Geol. Surv., Bull. 267, 1905, 50 pages.

tered coves along old shore lines seem to have afforded the maximum favorable conditions.

SEDIGENETIC AND IGNEOGENETIC ORES.

It will be noticed that the ores so far discussed are those of the common metals, the ores in which it is necessary to have a considerable quantity of metal present in order to make an ore. Of the rarer metals gold is known only by trace, silver occurs to the amount usually of one to two ounces per ton, arsenic and antimony are practically unknown. Nickel and cobalt are found in quantities of commercial importance at Mine La Motte, and cadmium in small quantities is a constant accompaniment of the Joplin ores. The ores are relatively simple in composition. Calcite, dolomite, barite and chalcedonic silica are almost the only gangue minerals. This simplicity of composition and the large weight of metal are characteristic features of ores which are found in unaltered sedimentary rocks. Gold-silver ores on the other hand are characteristically complex, and the precious metals are accompanied by a wide variety of other metals and of gangue minerals. The complex ores accompany igneous rocks, and the difference between the two classes is believed to be genetic. Recently the writer has suggested that those ores in whose production the processes of sedimentation are essential may be called sedi-genetic, while those in whose formation igneous activities are necessary may be characterized as igneo-genetic. Where the two sets of agencies co-operate the terms sedi-igneo-genetic or igeno-sedi-genetic may be used according to where it is desired to place the emphasis.[1]

The processes which result in the formation of sedi-genetic ores show striking resemblances to certain metallurgical processes —namely, wet concentration and hydro-metallurgy. Erosion may be regarded as a process of wet crushing or of crushing in solution. In nature it is carried out on the grandest scale, and instead of tons, cubic miles of rock are ground up and leached.

[1] "Sedigenetic and Igneogenetic Ores," ECONOMIC GEOLOGY, Vol. 1, 1906, pp. 331–339.

The natural solvents, it is true, are weak, but they are abundant, and unlimited time is available for their work. It is well known that a very large number of ore-forming minerals are more or less soluble in ordinary ground water, and in the destruction of large land masses immense quantities of these minerals must go into solution.

Sedimentation proper is essentially a concentrating and a precipitating process. It is a great agency for bringing like to like. It is powerful, is present whenever land and water meet, and has continued in activity through ages and eons. It seems altogether fitting that it should be appealed to in accounting for those ore deposits in whose productions tons of metal must have been concentrated from miles of rock. Other deposits, those in which ounces only of metal need be brought together to give value to the ore, may be referred to the temporary activities of igneous forces; activities which operate through limited time over limited areas, but which by way of compensation involve forces qualitatively more powerful and bring into operation solvents and pressures not available in the other cycle. When the two sets of forces both operate we may get deposits not only large but complex as at Leadville, but in general the deposits which are important because of their size and their high content of metal are believed to represent mainly the activities of the sedimentary cycle.

The ores of the Mississippi Valley are typically sedi-genetic, and to completely interpret them it is necessary to have much fuller knowledge of the paleogeography than we now possess.

In the case of a metalliferous province characterized by sedi-genetic ores the relation of the ores to the geologic history is evidently closed. Where igneo-genetic ores prevail the petrographic province must be worked out with equal care. Igneo-genetic ores may occur in the midst of a province characterized by sedi-genetic ores, since the essential factor in their concentration is the action of igneous forces which are relatively local. In the Mississippi Valley the ores of western Kentucky and southern Illinois are believed to supply a case in point.[1] In this small

[1] Bain, H. F., "The Fluorspar Deposits of Southern Illinois," U. S. Geol. Surv., Bull. 255, 1905, 75 pages.

district galena and blende occur, accompanied by pyrite, chalcopyrite, and stibnite, and with large amounts of fluorspar and crystalline quartz. In contrast with that found elsewhere in the valley the galena is somewhat argentiferous. Stibnite and fluorspar are found in none of the other districts described, and in its general complexity the ore of this district is more like that of the west than that of the other valley districts. This resemblance extends to the form of the deposits, which are veins following extensive fault fissures. The presence of igneous dikes near the veins further tends to set off these deposits from those of Missouri and Wisconsin and to link them with southwestern Arkansas and the Rocky Mountain region. It is believed indeed that they are igneo-sedi-genetic, and that heated waters of deep source played an important part in their production. Their presence in the valley, in the striking contrast which they afford to the other ores of the region, tends to confirm the conclusions already drawn as to the sedi-genetic nature of the bulk of the Mississippi Valley ores.

THE GEOLOGY OF THE CUYUNA IRON RANGE, MINNESOTA.[1]

C. K. Leith.

The Cuyuna iron range is the most recently discovered range in the Lake Superior region and as such is receiving a large share of attention. It lies along the line of the Northern Pacific Railway, near the Mississippi River in the vicinity of the towns of Brainerd, Deerwood and Aitkin, in Crow Wing, Aitkin and Morrison counties in north central Minnesota. Its boundaries are still being extended and few would care to draw limits in any direction. The area of present greatest activity lies to the south and east of the Mississippi River in townships 43, 44, 45, 46, 47, and 48 north, ranges 28, 29, 30, 31, and 32 west.

The Cuyuna district has almost none of the external aspects commonly associated with a Lake Superior iron range. The Cornishman's classic remark concerning the location of ore, "Where it is, there it is," would apparently explain the location of the Cuyuna Range, so far as surface appearances go. The country is nearly flat, heavily covered with glacial drift, and carries numerous glacial lakes. It has been wooded, but the most of the timber has been taken off and the area is now dotted with small farms. The conspicuous topographic ranges of the producing Lake Superior iron districts are lacking, as well as the numerous rock exposures.

The first discovery of ore in the district was made in 1904 by drilling directed by Mr. Cuyler Adams and associates along a line of magnetic attraction found by Mr. Adams in the vicinity of his summer home at Deerwood. Since that time drilling has been carried on without interruption and in increasing amount. A single test shaft has been sunk through the surface into the ore and gives the only glimpse of the formation which is thus far

[1] In this paper no attempt has been made to cover purely economic features.

to be had in the district except in drill cores. No ore has yet been shipped.

For some time previous to the beginning of the drilling, geologists had suspected the existence of iron formation in this district. The general geological map of Minnesota, published by the Minnesota Geological and Natural History Survey in 1901, showed this area as occupied by a southwestern extension of Mesabi slates and quartzites. In 1903 the writer published a sketch showing the hypothetical extension of the Mesabi iron-bearing formation to the southwest, through the since-discovered Cuyuna district. A similar view of the geological possibilities was held by Mr. W. N. Merriam, geologist for the United States Steel Corporation. The reasons for such geological inferences will appear later.

From the information so far available, consisting largely of drill samples, the succession of rocks for the Cuyuna district, from the base upward, is as follows:

Quartzite and its altered equivalents, quartzose, micaceous and hornblende schists.

Iron formation, consisting principally of iron carbonate where unaltered, but largely altered to amphibole-magnetite rock, ferruginous slates, and iron ore. The ores thus far found are soft, reddish, slightly hydrated hematite, reddish slaty hematite, and hard, blue, banded, siliceous magnetite and hematite.

Chloritic and carbonaceous slate, interbedded in its lower part with iron formation.

Intrusive granite and diorite, principally the latter.

Cretaceous sediments.

Glacial drift, 80 to 350 feet.

It is possible that some of the igneous rock is really older than the sedimentary series, and lies unconformably beneath it, but no evidence of this has yet been found and the structural relations do not favor this view.

So far as the sedimentary rocks go, the emphasis should be placed on the altered phases, for they have all been much metamorphosed. Failure to recognize the schists as parts of the sedimentary series has caused confusion in the local interpretation of drill records. The changes in the quartzite and slate to schists are the typical anamorphic changes of the zone of rock flowage.

When subsequently exposed at the surface there has been a leaching out of all of the basic constituents, leaving light-colored, soft, kaolinic and quartzose schists. This action is most conspicuous in their upper fifteen or twenty feet. The iron formation, originally mainly iron carbonate, has also undergone anamorphism, resulting in the development of amphibole-magnetite rocks essentially similar to amphibole-magnetite rocks wherever they are found in other parts of the Lake Superior region. This action, however, was not sufficiently effective to destroy a large part of the iron carbonate constituting the original mass of the formation. When exposed to weathering, the amphibole-magnetite rocks have remained substantially as they were, being very resistant, although becoming somewhat softer. The iron carbonate has been altered to iron ore. The gradation phases between the iron carbonate and slate have become ferruginous slates.

The anamorphism of the Cuyuna series is probably to be explained in large part by the existence of intrusives in the area itself and to the west and south of it.

The sedimentary series has been folded into a series of repeated folds, as shown by drilling and magnetic work, and erosion has cut off the top of the anticlines, exposing the iron formation in a number of belts, in general parallel, but presumably coming together at the ends of the folds. The dips are thus for the most part high, in the neighborhood of 80°, although near the crests of the folds they are less. The folding has been accompanied by the development of cleavage in the softer layers, especially in the softer slates. Where the cleavage can be definitely distinguished from the bedding, there is usually a slight angle between them, and the cleavage has the steeper dip. The iron formation itself is less affected by the cleavage than the slate.

The ores constitute the altered and concentrated upper parts of the steeply dipping iron formation strata exposed by the erosion of the anticlines. The hanging wall is commonly chloritic slate and iron carbonate in varying proportions and degrees of alteration; the foot-wall is either a quartz schist or amphibole-

magnetite schist. Intrusives complicate these relations in many deposits, suggesting that the presence of these rocks has favored the development of the ore deposits. This is yet to be proved.

The ore bodies thus far found seem to be in the form of lenses 1 to 250 feet in thickness, with their longer dimensions parallel to the highly tilted bedding of the series. It is probable also that several parallel or overlapping lenses may be present, judging from analogy with the lower part of the Animikie series elsewhere in the Lake Superior region, as in the Paint River, Crystal Falls, and western Menominee country. Along the strike these lenses pinch out or widen, the change often being accompanied by a change in grade of the ore. It is difficult to tell from the present state of exploration just how far the parallel lenses are independent lenses in the same general formation and how far they may be the result of duplication by folding. The broader features of distribution are undoubtedly to be explained by folding. There is a narrow zone of iron formation extending from east of Aitkin southwest past Deerwood and Brainerd and for some distance west of the Mississippi river, as shown by magnetic attractions and by drilling. This is made up of a large number of short parallel and overlapping belts. Whether these minor belts are repeated by folding or whether they are parallel, independent lenses is not known. Six miles to the north, however, in the vicinity of Rabbit Lake, there is again a belt of iron formation which is undoubtedly brought up here by folding, for if it were an independent belt in a monoclinal succession it would imply too great a thickness of intervening strata. Still farther to the northwest between Rabbit Lake and the Mississippi River are at least two more belts of iron formation repeated by folding. Whether the folds reappear again elsewhere prospectors are now trying to determine.

The rock surface beneath the drift shows local variations of 100 feet or more, and between widely separated points, because of the general slope of the surface, may show a difference of elevation of as much as 250 feet. Frequently the soft hanging-wall slates are found to be at lower elevations because of erosion than

the harder iron formation or the foot-wall quartzite adjacent, as for instance near the Pickands, Mather & Company's shaft in Sec. 8, 45–29. Notwithstanding these local irregularities of the surface, it is in a broad way relatively flat. At many places in the district and in adjacent parts of Minnesota, Cretaceous deposits are found just above the rock surface and beneath the drift, suggesting that this flat surface may be part of a pre-Cretaceous base level or peneplain. The Cuyuna district contrasts in topography of the rock surface with the producing ranges of the Lake Superior region, where there is usually a marked ridge or range giving a head to the percolating surface waters of from 200 to 500 feet and making it possible for the waters to circulate vigorously and accomplish ore concentration to considerable depths where structural conditions allow. This suggests the inference that in the Cuyuna district vigorously circulating ore-concentrating waters may not have been effective to so great a depth as in other Lake Superior iron ranges. On the other hand, the ores were developed before the base level, and before reaching the present base level, there may have been greater topographic relief, which would have aided the alteration of the rocks and concentration of the ore to a greater depth than would the present relief. The existence of the heavy mantle of weathered material over the area may represent a remnant of the weathered material which in the other districts has been removed by glacial erosion. It is obvious that the Cuyuna district has been one in which glacial deposition has predominated over glacial erosion. When it is remembered that in the other Lake Superior districts glacial erosion has probably removed large amounts of iron ore, the lack of glacial erosion in the Cuyuna district may not be an unfavorable indication.

The Cuyuna sediments probably belong in the same series with the slates and schists of the Carlton, Cloquet, and Little Falls areas. They show many similarities in lithology, structure and metamorphism, and are geographically contiguous. Drilling near Aitkin and near Cedar Lake to the southwest shows the same pyritic and carbonaceous phases of slate as have been explored for

coal in the vicinity of Mahtowa. Professor Hall[1] some years ago showed that the slates in the vicinity of Carlton and Cloquet, when followed off to the southwest toward the more abundant granite areas, become progressively more metamorphosed and toward Little Falls area may only with difficulty be recognized as sedimentary rocks.

Succession and lithology are in accord with distribution and general structural relations in pointing to the identity of the Cuyuna-Carlton-Little Falls series with the Upper Huronian or Animikie of the Lake Superior region, which includes the Mesabi series to the north and the Gogebic series in Michigan to the southeast. The Animikie as a whole consists of a great slate formation two miles or more thick, underlain by an iron formation of varying thickness, but averaging perhaps a thousand feet, and this in turn underlain by quartzite varying from 1 to 200 feet in thickness. Exploration has not yet gone far enough to warrant a satisfactory estimate of the thickness of the Cuyuna formations, but the information so far developed is in accord with the figures given for the Animikie series as a whole, with the exception of the iron formation, which thus far has not been found to be as thick as the average for the Lake Superior region. The Cuyuna range is separated from the Mesabi range on the northeast by a flat swamp and lake area perhaps thirty miles wide, which completely lacks rock exposures. The Animikie series in the Mesabi district dips to the south under this low, flat area at an angle varying from 4° to 20°. It has long been obvious that the series here disappearing under the surface might somewhere be brought up to the south by folding.

In the Gogebic range, on the south side of Lake Superior, a similar series dips at an average of 60° toward the northwest beneath the Lake Superior basin, and it has long been thought that this series represents the Mesabi series as it comes up again on the south side of the lake. An examination of the general structure of the west end of the Lake Superior basin, however,

[1] "The Keewatin Area of Eastern and Central Minnesota," by C. W. Hall, *Bull. Geol Soc. Am.*, Vol. 12, 1901, pp. 243–376.

shows that the structure of the area between these two districts is not that of a simple syncline, but of a syncline in which there are subordinate anticlines, *i. e.,* a synclinorium. One of these subordinate anticlines runs west and southwest from Duluth toward Little Falls and vicinity on the Mississippi River. If the Animikie series comes to the surface anywhere between the Mesabi range on the north and the Gogebic range on the south, it should therefore appear in this subordinate anticlinal fold in the western part of the general synclinorium connecting these two regions, and it was on this hypothesis that the extension of the Mesabi and Gogebic iron formation was drawn by geologists through the present Cuyuna district, which lies near the north side of this subordinate anticlinal fold. The existence of a quartzite exposure at Dam Lake near Kimberly, and near Rabbit Lake as shown by drill records, points to the fact that here erosion has cut down to the lower part of the Animikie series as it would in truncating an anticline. The course of the Mississippi River itself suggests the existence of the anticline in the vicinity of the Cuyuna Range, for, after crossing the Mesabi range, it flows south until it reaches the Cuyuna district and then turns suddenly westward as though deflected along the anticline toward a lower point of escape. Where it does break across, as at Little Falls, rocks are exposed.

The Carlton and Cloquet slates were early assigned by Irving and other geologists to the Upper Huronian, but they were later referred by Spurr to the Lower Huronian because of their greater metamorphism and folding than the Upper Huronian slates in the Mesabi district to the north and because they are intruded by granites supposed to be of Lower Huronian age. It is now known that the Upper Huronian series of the Mesabi district is also intruded by granite. The facts developed in the Cuyuna district seem to confirm Irving's view of the correlation.

In view of the probable equivalence of the Cuyuna and Carlton series and the occurrence of small iron carbonate bands and nodules in the slates about Carlton and Cloquet and southwestward, similar to the broader bands in the Cuyuna area, the ques-

tion naturally arises why erosion should not somewhere in this great exposed slate between Carlton, Cloquet and Little Falls area uncover the lower part of the Animikie series—in other words, the iron formation. It may be that the crest of the anticline runs parallel with the Cuyuna district itself, allowing erosion to cut down here only into the main iron formation, while to the south and southeast the thick capping of slates has not been removed, or it may be that the existence of great masses of intrusive granite and diabase and the intense metamorphism which they have accomplished have prevented erosion of the surface or have made the conditions unfavorable for the direct oxidation of the iron formation under surface katamorphic conditions. Certainly there are not yet enough facts available to warrant the assertion that the iron formation may not yet be found in this area.

THE IRON ORES OF THE SALISBURY DISTRICT OF CONNECTICUT, NEW YORK AND MASSACHUSETTS.

WILLIAM HERBERT HOBBS.

INTRODUCTORY.

The iron which comes into the market under the name of "Salisbury iron" is smelted from limonite ores mined in northwestern Litchfield County, Connecticut; Berkshire Co., Mass., and portions of Dutchess and Columbia counties in the State of New York. The ore was first mined, and much the largest amount of ore has now for a long time been obtained at mines situated within the town of Salisbury, Connecticut. No geological report seems to have been made upon this ore district as a whole, though many widely scattered papers have made reference to it, and together constitute a considerable body of scientific information.

In spite of the rather low grade of the ores (40 to 50 and exceptionally 55 to 57 per cent. of metallic iron) and the recent vast development of iron mining within the Lake Superior region, the Salisbury mines continue to be worked. This is largely due to the peculiar properties of the ore; particularly its high content of manganese and its low percentage of phosphorus, and to the methods of smelting and founding which are employed; the furnaces of the Salisbury and Richmond regions being among the few still left in America which use charcoal as fuel. The pig iron produced from these ores is especially adapted to the manufacture of car wheels, since it is of sufficient strength to resist the strains and shocks to which the wheel body is subjected, and has further the property of taking a deep chill, so that the tread and flange of the wheel can be made to withstand the wear upon them. That the fame of the Salisbury iron for this purpose is well founded has been amply demonstrated by tests carried out by Thurston and others.

HISTORY.

Iron was mined in Salisbury at least as early as 1734, the pioneer forge, with a capacity of one hundred and fifty pounds of iron for each charge, having been erected in that year in the village of Lime Rock. The ore for it was furnished from the "Davis" or "Forbes" pit at Lakeville, then known as the "Hendricks."

In 1781 a forge had been erected at Mount Riga on the summit plain of the Mount Washington mass, nearly one thousand feet above the mines in the valley.

In 1830 the first foundry for remelting pig iron was built at Lime Rock and soon came into the possession of Mr. Milo Barnum, the founder of the Barnum Richardson Company. This company now controls all of the ore that is mined within the Salisbury district proper, and has also an interest in the Richmond Iron Company, which operates the "Cone" mine in the Richmond district.

The mines at Salisbury, which are known as the "Old Hill," the "Chatfield" and the "Davis," were acquired by the Barnum Richardson Company, and have now been worked for periods of about one hundred, seventy-five and one hundred and seventy years respectively. Other mines of the region were soon purchased by the company, the greater number being near the eastern, southern or western margins of the great elevated mass situated near the common boundaries of Connecticut, Massachusetts and New York, and generally known as Mount Washington. As time went on the Barnum Richardson Company acquired many other properties in the vicinity, though most of them have now been abandoned and are so flooded with water as to afford few facilities for inspection.

Charcoal blast furnaces for the smelting of the Salisbury ores have been situated at Lime Rock, Falls Village, East Canaan, Chapinville, Cornwall Bridge, Huntsville, Amenia, Sharon Valley, Millerton, Mount Riga and Copake, all in or near the mining district. In the Richmond district furnaces are located at Richmond, West Stockbridge, Van Deusenville, Cheshire, Lanesboro

and Lenox Furnace. Only the furnaces at Lime Rock, Canaan, Richmond and Van Deusenville are now in use.

DISTRIBUTION OF THE MINES.

The greater number of the iron mines of the Salisbury district are located either at or near the boundary of the areas of Hudson schist with those of the Stockbridge dolomite. In this regard they have the same position as most of the other limonite deposits which have been opened along the base of the Appalachian Mountain system from Vermont to Alabama. A further fact of distribution which is of much significance is the arrangement of the mines of the Salisbury group about the base of the elevated area of Mount Washington. This mountain mass rises abruptly to heights of sixteen hundred to eighteen hundred feet above the level of the valley surrounding it. Its greatest length is seventeen miles, and its maximum breadth about six miles (see Fig. 11). The more important of the exploited ore beds form a nearly continuous series encircling the mountain mass at its base.

As properly included with the group of mines bordering on the Mount Washington mass should be mentioned those which extend southward along the line of the Ten Mile River and the Harlem River Railroad; which mines, with the last nine of the above, form a linear series which may be conveniently termed the Ten Mile series.

A subordinate group of iron mines, having similar geological relations to those of the Salisbury region, are situated in the West Stockbridge Valley, Massachusetts, between West Stockbridge and Lenox Mountains on the east, Maple Hill and Harvey Mountain on the south, and Cunningham Hill and Perry Peak upon the west. These mines may be spoken of collectively as the Richmond group. Of this series the only mine now operated is the "Cone" in the town of Richmond.

GEOLOGY OF THE DISTRICT.

Geological Horizons of the Ores.—The district within which the Salisbury ores are found is one of Cambro-Ordovician rocks,

FIG. 11. Topographic map showing the limonite mines located at the base and encircling the elevated areas.

including in the greater part of the area only the Stockbridge dolomite and the overlying Hudson (or Berkshire) schist. The first mentioned formation is one of dolomitic crystalline limestone of varying coarseness of texture, within which are crystallized out a number of metamorphic minerals, particularly, however, muscovite, biotite, malacolite, and occasionally tremolite and phlogopite. In color the rock is either white, grey or variegated blue-grey and white. The Hudson schist is a biotitic or muscovitic and graphitic schist, which frequently exhibits porphyritic metamorphic minerals, the more abundant of which are garnet, staurolite, microcline, or albite. Locally this rock is largely composed of chlorite and magnetite, and occasionally also it includes tourmalines. In places it is inter-stratified with the underlying Stockbridge dolomite, and occasionally it passes through intermediate calcareous schists into that formation.

For all, save the isolated "Kent" mine the Stockbridge dolomite and the Hudson schist are the only formations which outcrop in connection with the ore-bodies. At the "Kent" mine the ore-body is not found in connection with dolomite, but on the fault border of Poughquag quartzite and Hudson schist. The Poughquag quartzite is normally a granular and more or less vitreous quartzite, but is locally very impure and grades into quartz schist and quartz gneiss.

The three formations of Poughquag quartzite, Stockbridge dolomite, and Hudson schist represent a conformable series extending from the lower Cambrian to the end of Ordovician time —a series complexly folded and subsequently faulted along many nearly vertical planes with generally small displacements. As will be more fully explained below, it is believed that the faults have played an important rôle in the concentration of the ore by solutions brought in along them and other fissures as trunk channels. Where small orographic blocks have been depressed between fault walls and subsequently covered by the impervious glacial deposits, the faults have served a further purpose of yielding pockets in which to concentrate the ores whenever schist has thus been enclosed by dolomite. A typical example of such a pocket is furnished by the "Davis" mine at Salisbury.

In order that the geological occurrence and the relations of the genesis of the ore to the structure of the enclosing rocks may be clearly understood, a few descriptions of the chief mines will be presented here.

The "Davis" Mine.—At the "Davis" mine the country rock is entirely Stockbridge dolomite, furnishing in this respect an apparent exception to the general rule, which is that the ore bodies follow the boundary of Stockbridge dolomite with Hudson or Berkshire schist. The locality is, however, quite near the boundary of the two formations, and upon study it is found that

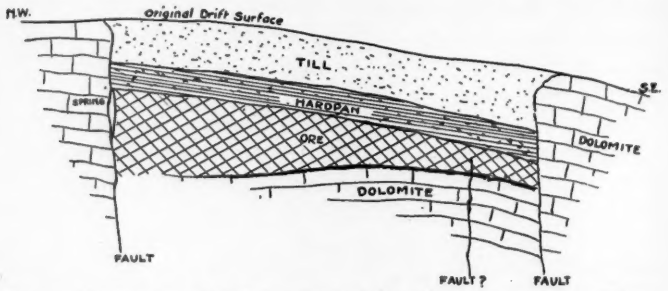

FIG. 12. Section across the "Davis" ore pit in a direction northwest-southeast.

a thin layer of the higher formation forms an impervious foot wall to the ore body. The excavations at the mine were made upon the site of a local swampy area, which from our present knowledge of the structure was occasioned by local springs rising along fault fissures. The geological structure at the locality is set forth in figure 12.

The average dip of limestone at the mine is 25° to 30° southeast. Beneath the ore body is a distinct roll in the formation which brings it somewhat higher in the eastern portion of the pit. To the southeast, and similarly to the northwest, the dolomite rises from the foot of the ore body in a steep wall toward the surface. These walls are believed to represent planes of faulting. Their strike is approximately N. 50° E. (see Fig. 13). Covering the ore body was a thick layer of stratified drift and till which is now well exposed upon the north wall of the pit.

The lower layers of this material were hardpan—a mixture of clay with glaciated pebbles—having an approximately uniform southeast dip of 20°. Above the hardpan was till, which with the harpan gave a total thickness of 75 feet in some places.

The base of the ore body is generally dolomite upon which is a thin layer (four to six feet) of hard black or grey slaty rock. The roll of the dolomite beneath the ore body was found to pitch 15° southwest. Toward the north wall of the pit the surface of the foot wall was warped in such a manner as to dip more nearly south. The fault walls bounding the pit upon the east and west have a dip of 70° or more to the northwest. From the massive dolomite of the steep western wall a copious

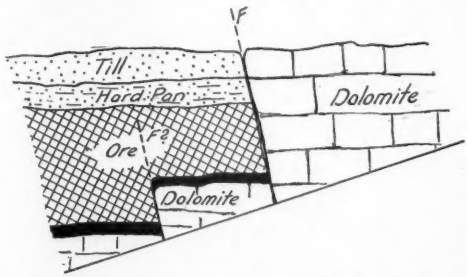

FIG. 13. Section at east side of "Davis" mine.

spring of cold water now issues and was probably in part responsible for the swampy area once located above the site of the present pit.

In addition to this spring there was another southeast of the swampy area and across the Lincoln City brook, which brook now enters the mine in a fall over the fault plane at the west and flows through the mine. A clue to the explanation for the concentration of the large body of ore at this mine seems to be afforded by the small remnant of schist formed near the north wall, and by the fault walls which so largely bound the ore body. The ore body appears to represent a sunken block in which the superior Hudson schist, now largely represented by ore, has been inset within bounding walls of dolomitic limestone. (See Fig. 12.)

The "Ore Hill" Mine.—The "Ore Hill" mines are at present entirely below ground, and are operated by the "caving" method. The older works at the locality, which were formerly known as the "Brook" pit, are a little to the north of the main incline, and, like most of the other mines of the Salisbury district, were operated from the surface by "open" methods. In the present workings the ore body is largely enclosed in Berkshire or Hudson schist, though a narrow layer of dolomite forms the greater part of the hanging wall. The dip of the rock is to the southeast at angles near 25°, and is subject to sudden changes. The incline descends along the foot wall at an angle of about 25°, but meets abrupt upward projections of this wall, which seem to

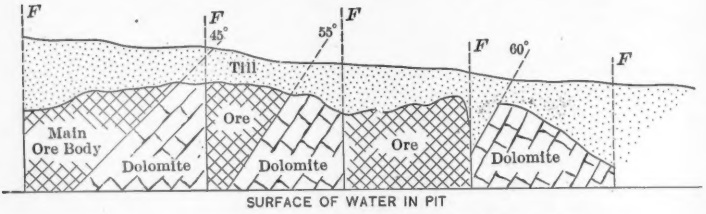

FIG. 14. Section on southeast wall of "Maltby" mine.

recur at regular intervals approximating forty or fifty feet. About 170 feet vertically below the entrance to the incline, and about thirty feet above the lowest level, this foot wall comes up in a nearly vertical plane so as to cut off the ore. The foot wall wherever examined was found to be graphitic schist like that of the Berkshire formation in the vicinity, and the ore appears to be largely a replacement of this rock, in which are found irregular block-like masses of so-called "white horse." The "white horse" somewhat resembles the dolomite, but has a soapy feel and contains 50 per cent. or more of ferric oxide. It appears to be a mixture of iron carbonate and talc, and elsewhere in the Salisbury district it has been mined for the iron which it contains. At the surface it weathers to a brown color owing to the hydration of the iron oxide. The interruptions in the foot wall above described appear to be due to faults, along

which the throw has been in most cases only a few feet. The hanging wall, which is exposed in the lowest level for a considerable distance, is a hard dolomitic marble, but in some places this is a garnetiferous and staurolitic schist. The peculiar relations at this mine are explained by interstratification of the

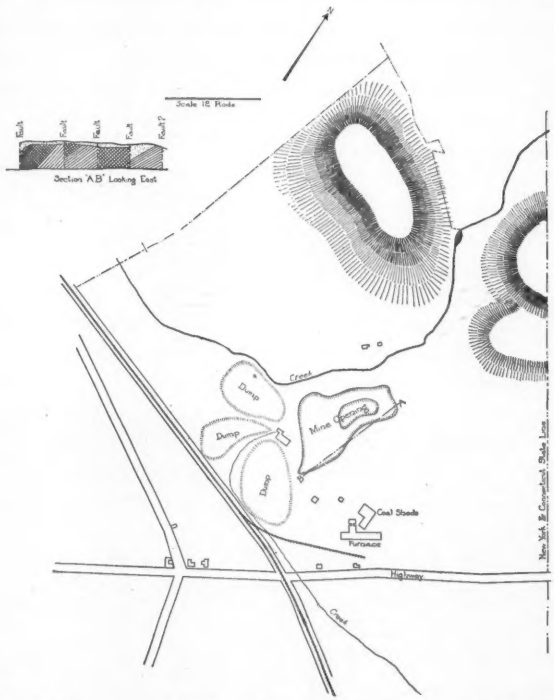

FIG. 15. Sketch map and section of the "Maltby" mine. (Modified from Putnam.)

dolomite and schist near their junction combined with normal faulting.

The "Maltby" Mine.—This pit was last operated by the Thomas Iron Company of Lehigh Valley, Pennsylvania, and abandoned in 1891. It is now filled with water to a depth of

about one hundred feet, so that only the upper walls are exposed to view. The data regarding the now covered portions were obtained from Mr. E. B. Manning, formerly manager of the mine. The pit is nearly circular and the interest of the geologist centers in the southeast wall which is shown in section in Fig. 14. A sketch plan of the mine is given in Fig. 15.

At least three small faults appear in the southeast wall of the

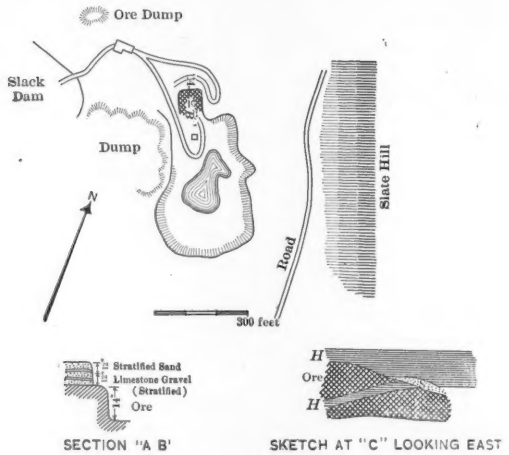

FIG. 16. Sketch plan of the "Cheever" mine. (After Putnam.)

mine, and bring up the dolomite and overlying ore in step-like succession as indicated in Fig. 14.

The middle ore body is distinctly wedge-shaped, and is cut off by a fault exposed in the wall. The strike of this fault is nearly N–S. From the north side of the pit the main body of ore was seen to have followed a direction N. 70° W. along the strike, and to dip about 45° N.

The "Cheever" or "Mt. Riga" Mine.—This mine is located on the west of the main highway about three miles north of Millerton and four miles south of Boston Corner. In the immediate vicinity of the mine no rock is now exposed, though lime-

stone appears some distance to the west. The foot wall was mica slate and had a gentle dip eastward toward the mass of Mt. Washington. The cover of the ore body was, as at so many mines of the district, hardpan,—a mixture of clay with glaciated pebbles,—and till. (See Fig. 16.) According to Putnam a tongue of the hard-pan was found forced under the ore.[1] The mine was operated as an open pit until a depth of 100 to 150 feet was reached. A shaft about ninety feet deep was put down from a point a little east of the margin of the pit. The mine was opened in 1865 and is estimated to have produced a total of about 61,000 tons of ore. It has now been abandoned for more than thirty years.

The "Kelly" Mine.—This pit has sometimes been called the "Upper Kelly" mine. On the authority of Mr. Theron Moore, who was recently the manager of the Weed mine and whose father operated the "Kelly" mine, the ore was found in pockets which were interrupted in a most irregular fashion. The ore was, moreover, intricately mixed with decomposed slate rock. This decomposed mica schist now covers the extensive dump, and is the normal type of Berkshire schist closely cut by joint planes in the manner already described for the "Ore Hill" mine.

The "Weed" Mine.—This mine, now owned by the Barnum Richardson Company, is located about two miles north of the station of Boston Corner. It has a foot wall of Berkshire schist, which dips eastward very regularly at an angle of about 25°. The ore lay directly upon this foot wall, and has been opened up in a north-south direction for nearly one fourth of a mile. As the foot wall was followed to greater and greater depths it became necessary to drift underground. As usual in the district, the cover consisted of clay and till. No dolomite outcrops near the mine, though there is little doubt that the valley area of the vicinity is in large part underlaid by this rock. The data for the "Weed" mine have been largely obtained from Mr. Theron Moore who was lately manager of the mine. The "Weed" was opened in 1780 and is estimated to have produced 168,000 tons of ore during the succeeding one hundred years. It has been operated until quite recently.

[1] Mining Industries of the U. S. Tenth Census, Vol. 15, 1880, p. 134.

The "Copake" Mine.—This open cut mine, now abandoned, is located in dolomite, and the peculiar "dead head" or "white horse" is found. The ore has in the past been reduced in the smelter at "Copake" Iron Works in the immediate vicinity.

The "Chatfield" Mine.—This once important mine is located a short distance southeast from the "Ore Hill" mines. The foot wall is of schist, which has a southeasterly dip of about 50° (Shepard) or in the same direction as at "Ore Hill." The cover

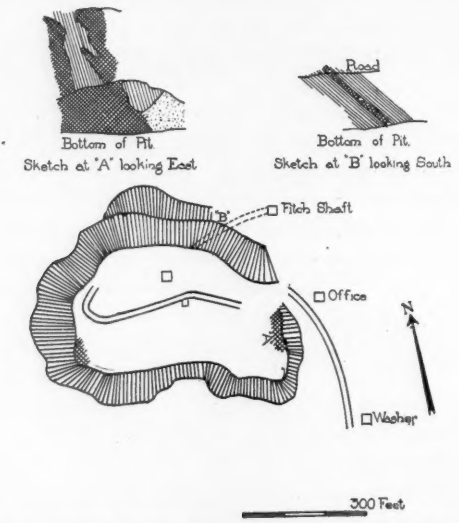

FIG. 17. Sketch of the "Chatfield" mine. (After Putnam.)

was of glacial material, which in places was as much as sixty feet in depth. The mine was opened in 1740, and between 1868 and 1880 it produced 168,000 tons of ore. The mine was first worked as an open pit until a depth of 120 feet had been reached. In 1880 a shaft was sunk from a point about three hundred feet east of the open pit and carried to a depth of about 140 feet. An abortive attempt was made to drift in the direction of the pit so as to run up beneath the ore body. Disappointed by the limitation of the ore body, the operation of the mine was aban-

doned, and it is now filled with water. A sketch map after Putnam is given in Fig. 17.

Putnam[1] describes a fault in the ore body located near the entrance to the pit. Shepard[2] states that in excavating a drain for a considerable distance through the schist the rock was found to be hard until within ten feet of the ore bed, where it became more or less soft from decomposition.

The "Manhattan" Mine.—This mine was operated as recently as 1902. The only rock exposed is dolomitic limestone, a com-

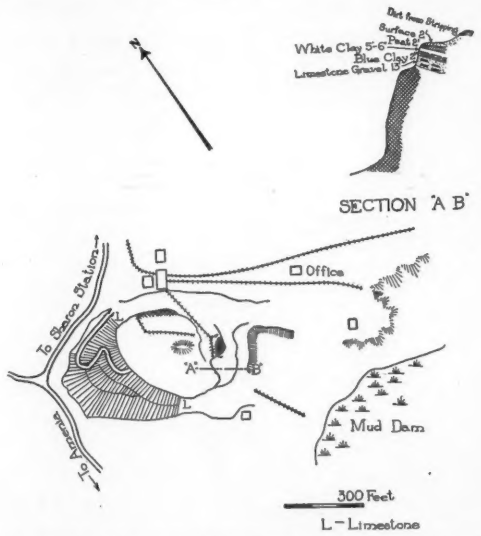

FIG. 18. Sketch plan of the "Manhattan" mine. (After Putnam.)

pact variety of which forms the south wall of the pit and dips towards the east. A similar dolomite is reported to form the foot wall of the relatively flat-lying ore body. On the southeast side of the pit is found the cover of pebbly till cemented by limonite, while east of and overlying the iron conglomerate is a bed

[1] Tenth Census of the United States, 1880, Vol. 15, p. 84.
[2] Report Geological Survey of Connecticut, 1837, p. 23.

of marly clay dipping eastward about 15° and filled with fresh-water gasteropods determined by Dr. Dall to be largely species of *Valvata tricarinata* Say and *Physa hetterostropha* Say; species which range from the Pliocene to the present.

The "Amenia" Mine.—The "Amenia" mine, to which is joined the "Gridley" mine upon the north, is located about one half mile southwest from Amenia station. This mine has been operated as recently as 1902. It has been developed principally along the strike of the rocks or about N. 40° E. To facilitate

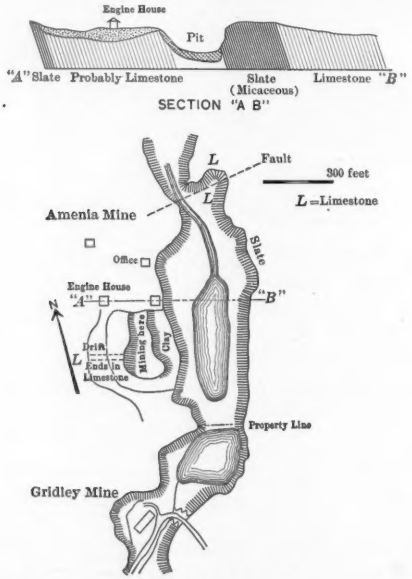

FIG. 19. Sketch map of the "Amenia" mine. (After Putnam.)

reference to the mine a sketch plan modified from one printed by Putnam is subjoined.

The southeast longitudinal wall of the mine consists largely of schist cut by frequent vertical joints, and exhibits in a striking manner the peculiar "sagging" often observed at iron mines

where alteration of the constituents and extensive leaching have gone on. The northeast wall of the pit is formed of much crumpled dolomite, the general dip of which is probably to the eastward. The ore body abutted against this wall which seems to mark the position of a fault. Specimens of fault breccia, the fragments in which are clear vein quartz and the cementing material ore, were picked up upon the dumps.

The "Camp" Mine.—This mine, located about two and a half miles northwest from Chapinville, was some fifty years ago a very productive iron mine, and twenty years later was reopened for manganese. The ore body laid as a wedge-shaped mass upon a foot wall of dolomite, which by Mr. William Pettee, formerly consulting engineer of the Barnum Richardson Co.,

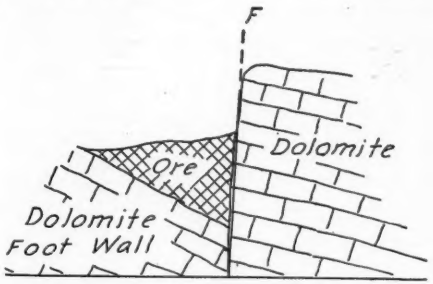

FIG. 20. Section of the "Camp" mine.

was estimated to dip 30° to the west. The ore body also met the same kind of rock upon a nearly vertical plane which formed the west wall, a wall still exposed at the mine (Fig. 20).

The "Cone" Mine.—The only mine now in operation in the Richmond district is the "Cone," located near the town of West Stockbridge. A section of the older mine of this name is given in Fig. 21.

The foot wall is here of dolomite, which dips to the southeastward at an angle of about 35° and has a strike of N. 30° E. To the southeast of the mine on the steep wall is found a decomposed variety of schist which is characterized by a soapy feel. The

workings are now underground, and the incline follows down some distance above the foot wall in a mass of yellow ochre. A layer of this material generally covers the foot wall and is utilized by the miners for following its general direction, though the workings are seldom carried down to the foot wall because it has been found too irregular to follow. The hanging wall is described as a "blue marl." This appears to be largely, if not wholly, of glacial origin, and from examination of the newer openings, hardpan. On the authority of Mr. Burget, the superintendent of the company, dolomite likewise forms the foot wall for the other now abandoned mines of the Richmond district. At the new opening of the "Cone" mine, a continuous body of ore has been penetrated to a depth of thirty feet or more without

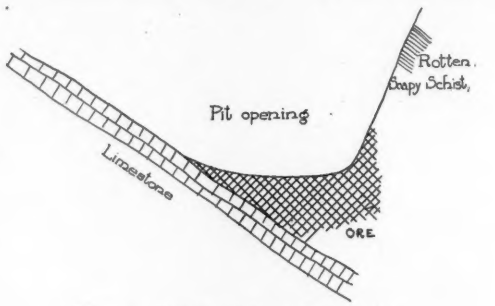

FIG. 21. Section of the "Cone" mine.

reaching its bottom. The ore is generally loose and admixed with considerable ochre.

The "Kent" Mine.—This mine, which is isolated from those of the Salisbury district proper, is located one and one half miles east-northeast from the station of South Kent, Connecticut. Unlike any of the other mines, also, it is situated, not at the contact of dolomite and schist, but of Berkshire schist with Poughquag quartzite. Shepard,[1] who examined the mine while it was still in active operation, draws a section in which the schist is shown to come in contact with the quartzite on basset edges. The char-

[1] *L. c.*, p. 20.

acter of the quartzite in immediate contact with the schist, makes it necessary, however, to explain the structure not by a single but by several faults. The considerable body of drift material in the neighborhood of the mine makes it impossible to follow these faults in detail. The mine has long been abandoned and is not likely to be reopened. The excavations made were, however, very extensive, and a shaft said to be 100 feet in depth was put down. Flaggy quartzite is found on the east side of the pit striking about N. 10° E. and dipping 60° east. There has, perhaps, been some falling in of this rock from the mine wall, but it is evident that a fault runs along the eastern wall. Fig. 22 shows a fault breccia from the mine, the fragments being quartzite cemented by ore.

FIG. 22. Specimen of fault breccia from the "Kent" mine.

COMPOSITION OF THE ORES.

General Statement.—The ores of the Salisbury district have been described as largely limonite, with which is associated a small amount of turgite, and in variable quantity ores of manganese. From certain of the mines, notably the "Ore Hill," "Amenia," and "Copake" mines, the so-called "dead-head" or "white horse" has also been mined. This latter material, generally described as iron carbonate, is usually but an impure variety of that mineral, since it generally contains considerable silica and a sericitic or talcose mineral.

The superiority of the Salisbury ores is largely to be ascribed to the low content of phosphorus and the high content of manganese; and these qualities are enhanced by the method of smelting in charcoal furnaces.

The following analyses of ores from the Salisbury district have been collected from various sources. The larger number have been made by Mr. J. S. Adam, of Canaan, Conn., formerly chemist for the Barnum, Richardson, Co., and the author's thanks are especially due to Mr. Adam for allowing these valu-

SALISBURY GROUP OF MINES (CONNECTICUT).

Name of Mine and Type of Ore.	Fe_2O_3	Mn_2O_3	SiO_2	S	P_2O_5	CaO	MgO	Analyst.	Date.
"Davis."	72.501	3.530	9.420	.019	.191	1.401	.015	J. S. Adam.	1879
" Top of bed. Selected	79.048	.678	5.085	.014	.156	.165	Tr.	"	"
" Black vein.	73.761	6.595	7.420	Tr.	.127	—	—	"	"
" Manganese.	1.105	87.241	.745	—	.071	Tr.	—	"	
"			10.870					J. Blodgett, Britton and Co.	
"	75.720	1.376	7.580	.082	.032		15.210	C. F. Chandler.	1875
"Old Hill."	73.510	.960	10.480	.070	.570		14.410	"	"
"	58.735	2.475	21.030	.019	.245	Tr.	Tr.	J. S. Adam.	1879
" (Weed right). Best ore	81.554	.725	5.145	.023	.280	.137	Tr.	"	"
" " Poor	41.890	.475	41.575	.105	.127	1.850	.776	"	"
"Brook Pit." No. 2			9.810					J. Blodgett, Britton and Co.	
" (White horse). Rich								J. S. Adam.	"
" " Poor								"	"
"Chatfield."	63.265	1.915	18.385	.031	.163	.315	—	"	"
" Black	63.980	8.605	13.985	.028	.234	.290	Tr.	"	"
"	78.136	.826	.630	.048	.501		13.857	C. F. Chandler.	1875
"Scoville."	71.114	2.065	14.430	.013	.463	—	—	J. S. Adam.	1879
" Manganese.	1.115[1]	84.850	.355	.327				"	"
"Camp." (Chapin)	Average sample from 50 tons of ore rock.							Tenth Census.	

	Al_2O_3	H_2O	Total.	Fe	Mn	S	P		
"Davis."	1.371	11.710	100.160	50.571	2.457	.019	.083	J. S. Adam.	1879
" Top of bed. Selected	3.591	11.910	100.649	55.334	.471	.014	.068	"	"
" Black vein.	.614	11.350	99.867	51.633	4.591	—	.055	"	"
" Manganese	—	10.020	99.574					"	
"				48.430	2.19	Tr.	.120	J. Blodgett, Britton and Co.	
"				53.000	.958	.082	.014	C. F. Chandler.	1875
"Old Hill."				51.450	.670	.070	.250	"	"
"	5.775	11.481	99.760	41.115	1.723	.019	.107	J. S. Adam.	1879
" (Weed right). Best ore	1.471	11.010	100.345	57.088	.504	.023	.122	"	"
" " Poor	3.995	9.670	100.463	29.323	.330	.105	.055	"	"
"Brook Pit." No. 2				50.220	.620	Tr.	.240	J. Blodgett, Britton and Co.	
" (White horse). Rich				35.420			.080	J. S. Adam.	"
" " Poor				35.130			.04	"	"
"Chatfield"	4.675	10.730	99.479	44.285	1.333	.031	.071	"	"
" Black	1.100	11.411	99.633	44.780	5.990	.028	.102	"	"
"				54.696	.576	.048	.219	C. F. Chandler.	1875
"Scoville."	1.938	10.720	100.743	49.780	1.430	.010	.200	J. S. Adam.	1879
" Manganese.		10.120			59.070		.143	"	"
"Camp" (Chapin)							1.000	Tenth Census.	

[1] With Al_2O_3.

"Chatfield"	4.675	10.730	99.479	44.285	1.333			"	"
" Black	1.100	11.411	99.633	44.780	5.990	.028	.102		
"				54.696	.576	.048	.219	C. F. Chandler.	1875
"Scoville."	1.938	10.720	100.743	49.780	1.430	.010	.200	J. S. Adam.	1879
" Manganese.		10.120			59.070		.143	"	"
"Camp" (Chapin)							1.000	Tenth Census.	

[1] With Al_2O_3.

TEN MILE GROUP OF MINES (NEW YORK).

Name of Mine and Type of Ore.	Fe_2O_3	Mn_2O_3	SiO_2	S	P_2O_5	CaO	MgO	Analyst.	Date.
"Copake." Rock and wash ore								Tenth Census.	
" (Dead Head). Carbonate.								"	
"Weed."			17.530					Millerton Iron Company.	
"								Tenth Census.	
"Reynolds."	60.41	.44	27.83[2]	.006		.22	.06	Chemist of Mill'n Iron Co.	
"	72.828	1.210	13.500	.071	.364	.730	Tr.	J. S. Adam.	1880
"Morgan."	61.77	1.65	22.04[2]		1.40	.17	.07	Chemist of Mill'n Iron Co.	
"Dakin." (Couch)								Tenth Census.	
"Mt. Riga."	63.840	.790	21.890	.407	1.107			J. S. Adam.	1881
"Maltby." Rock ore	Average sample from 500 tons of rock ore.							Tenth Census.	
" Wash ore	" " " 400 tons of wash ore.							"	
"Indian Pond."	69.167	1.442	13.000	.099	.531	.340	Tr.	J. S. Adam.	1879
Sharon. (Manhattan.)	72.40	0.64	13.20	.34	Tr.	.91		F. W. Dahue.	
"Sharon." (Manhattan.)	Average sample from three carloads of washed ore.							Tenth Census.	
" "	Selected sample of clippings from crystallized ore with jet black polished surface.							"	
"Gridley," Amenia, "White Horse" ore.		1.90[1]			.30	.61	.45	J. B. Britton.	
"Amenia."	70.931	.860	11.550	.028	.479	.380	Tr.	J. S. Adam.	1879
"			15.08					Ledon and Company.	1901
" Roasted carbonate	77.202	3.005	8.240	.224	.275	1.650	1.167	Booth, Garrett, and Blair.	1883
"Dover."		4.680	11.770	.049	.726			J. S. Adam.	1880
"Pawling."	63.840	1.830	20.680	.342	.265			"	1881

[1] MnO.

[2] Insoluble residue.

TEN MILE GROUP OF MINES (NEW YORK).—*Continued.*

Name of Mine and Type of Ore.	Al_2O_3	H_2O	Total.	Fe	Mn	S	P	Analyst.	Date.
"Copake." Rock and wash ore				46.790			.424	Tenth Census.	
" (Dead Head). Carbonate				30.820			.248	"	
"Weed."	6.060			43.000		none	.110	Millerton Iron Company.	
"				40.210			.083	Tenth Census.	
"Reynolds."	.74	9.92	99.63	42.29		.006	.124	Chemist of Mill'n Iron Co.	
"	1.308	10.250	100.261	50.979	.842	.071	.158	J. S. Adam.	1880
"Morgan."	2.08	10.78	99.96	43.24			.61	Chemist of Mill'n Iron Co.	
"Dakin." (Couch)				40.350			.357	Tenth Census.	
"Mt. Riga."	1.213	11.600	100.757	44.690	.550	.407	.445	J. S. Adam.	18.1
"Maltby." Rock ore				48.050			.215	Tenth Census.	
" Wash ore				41.000			.156	"	
"Indian Pond."	3.698	11.470	99.749	48.417	1.002	.099	.231	J. S. Adam.	1879
"Sharon." (Manhattan.)	6.51	4.91[3]	99.62	50.68				F. W. Dahue.	
"Sharon." (Manhattan.)				47.770			.086	Tenth Census.	
" "				50.130			.038	"	
"Gridley," Amenia, "White Horse" ore.	1.47	24.87[4]		46.06			.13	J. B. Britton.	
"Amenia."	3.662	11.540	99.430	50.928	.598	.028	.209	J. S. Adam.	1879
"				48.33		.024	.150	Ledon and Company.	1901
" Roasted carbonate	2.768	5.684[5]		54.042	2.165		.120	Booth, Garrett, and Blair.	1883
"Dover."					3.260	.049	.318	J. S. Adam.	1880
"Pawling."	2.155	10.640	99.752	44.680	1.270	.340	.110	"	1881

[3] Also .71 CO_2.

[4] CO_2.

[5] Loss on ignition.

Loss on ignition.

ISOLATED MINES IN LITCHFIELD COUNTY, CONNECTICUT.

Name of Mine and Kind of Ore.	Fe_2O_3	Mn_2O_3	SiO_2	S	P_2O_5	CaO	MgO	Analyst.	Date.
"Tobey Hill" (Canaan)	61.827	.365	23.125	Tr.	1.970	—	—	J. S. Adam.	1879
"Kent" (South Kent)	80.500	.210	6.140	.115	.722	—	Tr.	"	1881
" Rock ore	Sample selected by averaging from 100 ton pile.							Tenth Census.	
" Washed ore	"	"	"	"	"	300 "	"	"	
" Iron breccia								"	

	Al_2O_3	H_2O	Total.	Fe	Mn	S	P		
"Tobey Hill" (Canaan)	2.798	9.570	99.655	43.279	.254	—	.860	J. S. Adam.	1879
"Kent" (South Kent)	1.228	11.440	100.355	56.350	.149	.115	.316	"	1881
" Rock ore				53.020			.315	Tenth Census.	
" Washed ore				50.480			.353	"	
" Iron breccia				30.820			.196	"	

RICHMOND GROUP OF MINES. (MASSACHUSETTS.)

Name of Mine and Type of Ore.	Fe_2O_3	Mn_2O_3	SiO_2	S	P_2O_5	CaO	MgO	Al_2O_3	Analyst.	Date.
"Cone."	61.540	2.890 MnO	19.880	.019	.311	.715	Tr.	3.180	J. S. Adam.	1879
" Picked sample	85.880	1.140 MnO	5.400		.007	.560	"Organic"		Chapman.	
" Low grade	51.500	3.500 MnO	34.500			1.500	"Organic Matter" .500		C. T. Jackson.	
" Average run	79.000	4.000 MnO	4.300			.700			"	
"Bacon." Brown	67.250	6.380 MnO	14.100	Tr.	1.660	.670	.310		Chapman.	
" Blue.	44.230	9.110 MnO	17.900	Tr.	1.270	.700	.500		"	
"Goodrich." Brown	78.910	.910 MnO	8.200	Tr.	.250	.100	Tr.		"	
" White carbonate ore	65.600	7.300 MnO	14.800	Tr.	.380	.090	Tr. "Organic Matter"		"	
"Chauncey Leet." No. 1	61.060	.760 MnO	23.700	Tr.	.520	.640		.220	"	
" " No. 2	69.280	.510	22.600	.007	.560	.040	.030		"	
"Leet."	60.245	3.230 MnO	20.745	.016	.312	.390		4.250	J. S. Adam.	1879
"Cheever." No. 2	61.000	4.080	21.600	.130	.580	.380				
"	65.637	3.310 MnO	15.175	.011	.552	Tr.	Tr.	3.983	"	1879
"Branch." No. 1	62.600	4.530	21.920	.020	.170					
"Shaker."	67.938	.510	12.485	.012	.920			6.152	"	1879
"Cheshire."	80.547	.520	4.830	.104	1.724			.739	"	1881
"Colby"	62.280	2.800	24.710		.810				"	
" Poor grade	47.735	10.605	20.860	.113	.889			9.985	"	1879
"Gates."	57.229	1.910	24.750	.092	.251	.490	Tr.	4.600	"	1880
"Pomeroy."			10.520							

RICHMOND GROUP OF MINES. (MASSACHUSETTS.)—*Continued.*

"Gates."	57.229	1.910	24.750	.092	.251	.490	Tr.	4.660	1880
"Pomeroy."			10.520						

RICHMOND GROUP OF MINES. (MASSACHUSETTS.)—*Continued.*

Name of Mine and Type of Ore.	H_2O	Total.	Fe	Mn	S	P	Ana'yst.	Date.
"Cone."	10.750	99.285	43.078	2.012	0.19	.135	J. S. Adam.	1879
" Picked sample	6.950		62.200				Chapman.	
" Low grade	9.000	100.500	36.050				C. T. Jackson.	
" Average run	12.000	100.000	55.300				"	
"Bacon." Brown	9.640	100.010	47.040				Chapman.	
" Blue			30.900				"	
"Goodrich." Brown			55.240				"	
" White carbonate ore			45.090				"	
"Chauncey Leet." No. 1	13.200	100.100	42.740				"	
" " No. 2	6.980	100.010	48.500				"	
"Leet."	10.070	99.253	42.172	2.248	.016	.136	J. S. Adam.	1879
"Cheever." No. 2	12.230		42.700					
"	11.620	100.288	45.946	2.304	.011	.241	"	1879
"Branch." No. 1	10.660	99.900	43.840					
"Shaker."	11.990	100.007	47.557	.355	.012	.402	"	1879
"Cheshire."	11.130	99.594	56.383	.362	.104	.754	"	1881
"Colby."	9.770		53.590	1.950		.353	"	
" Poor grade	10.180	100.367	33.415	7.383	.113	.388	"	1879
'Gates."	11.170	100.492	40.060	1.329	.092	.109	"	1880
"Pomeroy."			49.370	1.094		.223		

able results to be made public. Others have been gathered from manuscript analyses in the possession of the mining company, and a few[1] have been taken from published papers. It will at once be apparent from inspection of the analyses that individual mines have their peculiarities of composition. The "Davis" ore is particularly valuable because of its high content of manganese, and this is to a less extent true of that from the "Ore Hill" mine. Richest of all, in this constituent, however, was the black ore of the "Chatfield" mine, and the genuine manganese ore from the "Scoville" pit. It thus appears that the ores richest in manganese are distributed in the bodies which occur along the eastern and southeastern base of the Mt. Washington mass. The mine at South Kent was abandoned on account of the high content of phosphorus.

The fact that zinc is associated in minute quantities with manganese in nature has been illustrated by the operation of the Salisbury smelters, even though it has not been indicated by the chemical analyses. The tendency of this element to sublime results in its collection in the throats of furnaces, from which it is recovered when the furnaces are "blown out."

THE ORIGIN OF THE ORES.

Elements to be Considered.—Any adequate theory of origin for the ores of the Salisbury district must take account of the following conditions: (1) In texture the greater proportion of the ore is that of a decomposed schist, though the exceptional "white horse" resembles the dolomite found in the district. (2) The mines are located at, or very near to, the boundary of Stockbridge dolomite and Berkshire schist; and, in the greater number of instances, both these rock types are in evidence at the mines. It has been shown also that in some instances in which the only rock exposed near the mine is dolomite, the mine workings reveal a thin layer of schist which forms an impervious foot wall. (3) The Salisbury mines are located near the base of considerable elevations, and most of them surround the mass

[1] *Trans. Am. Inst. Min. Eng.*, Vol. 5, 1877, p. 235.

of Mount Washington, which by its superior height dominates all the country within a radius of thirty miles or more. This upland area consists almost throughout of the Berkshire schist. (4) The ore bodies show marked irregularity of form and are frequently terminated by steep rock walls. This abruptness of the boundary, coupled with the rather general uniformity in the dip, and with the presence of breccia in some instances, is to be accounted for by faulting, though the throws upon the individual fault planes are in most cases small. Faults at the "Kent," "Chatfield," and "Davis" mines have been mentioned by Shepard and Putnam, respectively, and the present writer has here described such structures from the "Davis," "Ore Hill," "Maltby," "Kent," "Camp," and "Amenia" mines. (5) At the Ore Hill mine interstratification of the dolomite and schist may be observed. (6) The schist which outcrops near the Ore Hill mines is closely jointed and so disintegrated, that it may generally be removed with a pick. This is especially true, also, of the "Kelly" and "Amenia" mines, and only less so of others. At the last mentioned mine, the sagging of the loose rock so often observed at ore pits, is well brought out. (7) From a number of mines "Fuller's earth" has been noted in association with the ore, and without exception the cover of the ore body has been found to be a relatively impervious layer of clay and till of glacial origin. A bed of marl, which forms a portion of the cover above the "Manhattan" mine at Sharon, contains fresh water shells whose range in age is from the Pliocene to the present. The underlying bed of till would, however, restrict them to the Pleistocene.

Earlier Theories.—Shepard in his report upon the geology of Connecticut[1] ascribes the occurrence of limonite within the Salisbury district to the decomposition of pyrite *in situ;* "since no perceptible derangement is discernible in the layers of the ore bed or want of conformity in them to the adjacent rock." Of the "Kent" bed he makes an exception, as this ore body is located along a fault and may have obtained accessions of iron from the decomposing gneiss higher up the slope.

[1] New Haven, 1837, p. 146.

Percival[2] five years later adopted Shepard's theory and laid additional stress upon the fact that the structure of the ore body is the same as that of the Berkshire schist? He mentions finding the same quartz lenses in each. This view is also quoted with approval by Hunt in a discussion of a paper by Prime.[3] Smock[4] ascribed the ores to changes from iron carbonate, which he says is found in some of the deeper workings. In the same year Dana[5] gave a concise statement of his views upon the origin of the ores, as a result of his extended studies upon the geology of the district. He believed that the source of the ore was the dolomite, in which the ore existed as spathic ore (siderite) which was laid down together with the calcite and dolomite upon the main mass of Stockbridge dolomite during its transition to the Berkshire schists. The wholly local occurrence of the iron carbonate, and the abrupt passage from it to the normal type of dolomite he did not explain. The loose character of the ore, he accounted for by the limonite developing from the siderite on fissures so as to form enclosing crusts, from within which the limestone was later carried away by solution. The decomposition of the slate or schist near the ore he thought was promoted by carbonated waters enriched by the carbonic oxide which had been set free in great quantities through the great oxidation of the iron; this water being considered effective to carry away the potash and other bases of the mica and feldspar so as to leave a residual clay.

It will be noted that all the above mentioned theories of origin of the Salisbury ores refer the source of iron to its presence in other minerals *in situ*, from which it has been derived through local processes of alteration. In Dana's theory the iron carbonate from which the limonite was assumed to be derived, was laid down in Ordovician time during the change of conditions of sedimentation which ushered in the Hudson formation.

[2] Report on the geology of Connecticut, New Haven, 1843, p. 132.

[3] *Trans. Am. Inst. Min. Eng.*, Vol. 3, 1875, p. 419.

[4] John C. Smock, Geologico-geographical distribution of the iron ores of the eastern United States, *ibid.*, Vol. 12, 1884, p. 137.

[5] J. D. Dana, "Note in the Making of the Limonite Ore Beds," *Am. Jour. Sci.* (3), Vol. 28, 1884, pp. 398–400.

In 1904 a paper was published by E. C. Eckel on the Salisbury iron mines.[6] With the observations recorded in this paper the writer cannot entirely agree. The statement that "faulting is decidedly uncommon in this region" does not seem to be borne out by the evidence. Putnam's fault in the ore-body at the Ore Hill mines (no longer open to inspection) is regarded as a mere slip in surface material. The conclusions from the study are stated to be in confirmation of the views of Hayes.

Eckel has two explanations for the formation of the ore bodies: (1) Replacement of limestone, either alone or associated with schist, by iron carbonate; and (2) (stated to be less important, more doubtful, and likely to occur in a gently folded area) "direct deposition probably as limonite, in a basin *on* or a cavity or cavern *in* a flat-lying limestone." This second type is said to be illustrated by the "Davis" mine, the largest in the district. The manner of replacement by iron carbonate in the more general explanation, is not discussed, and no weight is attached to the high upland areas on the margin of which the ores are found.

Hypothesis of the Writer.—The view of the writer may be concisely stated as follows:

1. The iron contained in the ores has not come from the alteration *in situ* of ferruginous minerals, formed either in the schist or in the dolomite at the time of their deposition, but has been introduced from some outside source through the agency of solutions affecting the replacement of the schist and dolomite locally, and generally along their contact. This outside source of the iron is with much probability the pyrite contained in the Berkshire schists of the adjacent elevated mass—for the larger number of mines Mt. Washington.

2. The ores were formed as replacements; the limonite of Berkshire schists and the "white horse" or iron carbonate of the Stockbridge dolomite. At the "Ore Hill" mine the sericitic character of the "white horse" indicates that the original rock

[6] E. C. Eckel, "Brown Hematite Deposits of Eastern New York and Western New England," *Eng. and Min. Jour.*, Vol. 78, September 15, 1904, pp. 432–434.

was a calcareous schist or micaceous dolomite, belonging to the transitional zone between the two named horizons.

3. The localization of the ores is accounted for: (1) By the proximity of Mt. Washington, or some other upland area, which produced a vigorous circulation; (2) by local fracturing along joint and fault plains, which not only concentrated the near-surface currents, but allowed the deeper currents of ascending waters to mingle with them; (3) by the depression of a block of much fissured schist within walls of the inferior dolomite and the partial covering of this block by a relatively impervious layer of clay or hard-pan. This type of "in-set" block while not universal, is yet of rather general application. Inasmuch as the fissures within the underlying dolomite become readily healed, the locally fractured schist block becomes a natural pocket through which the waters circulate, and from which they escape upward through a relatively small number of trunk channels—generally along the bounding fault planes, or at places where the continuity of the clay cover is interrupted. At the "Manhattan Mine" in Sharon, the mantling drift cover has been in places cemented by limonite into an iron conglomerate. It is this fact which points to the continuance of the process since the close of the Glacial epoch.

4. The iron was probably carried in solution in part as sulphate, particularly in the near-surface solutions, but more largely in the form of ferrous carbonate by the ascending currents of the deeper flow. As has been shown by Van Hise,[1] the mingling of the near-surface solutions which carry free oxygen with the carbonated ascending solution, results in the formation of the hydrated iron oxide and the liberation of free carbonic acid, according to the formula:

$$2FeCO_3 + nH_2O + O = Fe_2O_3 + nH_2O + 2CO_2$$

5. The time of deposition of the ores may have been long continued. The impervious layers of the drift form the hanging walls, hence the time of formation of the ores must have been

[1] Monograph 47, U. S. Geological Survey.

late Glacial or post-Glacial, though some replacements of the schist and dolomite may have taken place before the covering of glacial material had been added, but this does not seem likely. It would be necessary to assume the existence of swampy areas and bog deposits, of which the ore body reveals no indication, and the general preservation of schist structure in the limonite beds speaks loudly for the pocket formation.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, South Bethlehem, Penna. The full name of the author should be attached to all communications.

HOW SHOULD FAULTS BE NAMED AND CLASSIFIED?

Sir:—I should like to correct Professor Jaggar's impression that in my text-book, "Geology Applied to Mining," I have confused the distinction between the vertical displacement of a fault and the displacement as measured on the fault plane. I am surprised at this mistake, since for ten years my publications on the subject have been very explicit on the matter of the necessity of not confounding these or other fault functions and nowhere have I expressed this more clearly than in the text-book quoted. Moreover, the quotation given by Professor Jaggar is abbreviated so that the statement contained is quite incorrect, as anyone can see by referring to the original (p. 159). In this text-book and in earlier publications I defined the displacement of a fault as seen in the vertical section and measured along the fault plane as *throw*. My reason for adopting this definition is shown from the following quotation from my Aspen report:

"It is sometimes possible to find out the amount and direction of movement immediately; but more often it must be indirectly calculated, and to do this it is important to have clearly in mind the nature and value of some of the principal functions of a fault movement, and to have specific terms by which to designate them. The terms already in use are of a rather vague and general character, resulting from the usual conception of a fault as a dislocation of strata. The four terms generally employed are displacement, throw, heave, and offset. The words displacement and throw are

used interchangeably, and commonly refer to the separation of beds by a fault as seen in a vertical section. Each of these terms is used by some to indicate the distance along the fault plane between the broken ends of the bed as seen in the section, and sometimes the perpendicular distance between the parts of such beds, projected if necessary. There is no agreement, however, which definitely assigns the terms to separate measurements, and indeed it is very common for a writer to use the terms interchangeably for one or the other function. Heave and offset are also used interchangeably, and are usually held to signify the perpendicular distance measured on a horizontal plane, such as the earth's surface, between portions—projected if necessary—of a bed separated by a fault.

"In mining work it is generally necessary to differentiate clearly the different functions of a fault movement, and I have adopted the following terms descriptive of the most important of these. These terms include nothing very novel in the way of nomenclature, but are intended simply to affix definite names to different things."

The different definitions adopted may be seen by referring to the monograph quoted or to the text-book in which they were repeated. There are many other fault functions other than those I have noted; but in these writings I considered that it would be superfluous to do more than point out the principles and to define what I considered the chief functions. Among the additional functions is that referred to by Professor Jaggar as *throw* and as used by him referring to the vertical displacement. In my system of nomenclature I have reserved the term *vertical displacement* for this function and have used this term in my work, though I have not included it specifically in the essay above quoted.

Concerning the main question raised by Dr. Ransome as to the retention and definition of the terms "reversed" and "normal" as applied to faulting, I can do no better than quote my definition in "Geology Applied to Mining," which I still hold:

"Most fault planes have an inclination or dip between the horizontal and vertical. When the rocks on the upper side have moved down, relative to the rock on the under side, the fault is called normal. If the reverse movement has taken place, the fault is called a reversed or thrust fault."

This definition takes cognizance only of the actual movement of one rock block, considered as if homogeneous, upon another, and does not take note of apparent geometrical complications

introduced by stratification or other elements disturbing homogeneity.

The terms "normal" and "reversed" are ancient, have a descriptive value, and I think should not be wholly discarded. According to my idea a fault movement along a strictly vertical plane or along a truly horizontal plane could not be described by either of the terms in question, but a fault along a plane having a dip between the horizontal and the vertical may be called normal if the upper side has moved downward relative to the lower side, and this would hold whatever the direction of the movement might be, provided it was not horizontal. Again, a fault where the upper side has moved down, at whatever angle, may be called reversed. But if along such an inclined fault plane the movement has been horizontal, then again the displacement cannot be included by either of the terms in question and must be described by a composite term.

J. E. SPURR.

Sir:—The current English nomenclature for faults has regarded displacements with reference to the vertical plane. The late Californian earthquake emphasizes the previously recognized fact of displacement in horizontal plane. As the shifting along stratigraphic planes is less apparent or even obscure it is probable that such dislocations will be found to be much more frequent than has been supposed; and in some regions may be the prevailing form. The necessity for recognition and discrimination in our terminology of the horizontal movement is evident. It may be desirable to restrict the old term "fault" to its commonly accepted implication, that is, to the dislocations involved in vertical movements, and to select some new term, like "shift," to express the horizontal or strata-plane displacements.

It is possible that the genetic distinction of "tension" and "compression" may be applicable to shifts as well as to faults; but the structural discrimination of "drop" (gravity) and "thrust" are clearly inapplicable.

The terms "normal" and "reverse" lack significance as regards both genesis and structure, and are misleading to students. The terms "tension" and "compression" are excellent in the philosophic discussion of the involved forces, though it may be difficult to apply them in specific cases. In description of structure, or the actual displacement, the terms "drop" or "gravity" faults and "thrust" (overthrust) faults are preferable.

With increasing knowledge of the variety and complexity of crustal displacements the limited nomenclature now in use will become inadequate, and other definitive or qualifying terms will be needed.

The following tabulation of the terms given above is offered as a basis for elaboration:

- Stratigraphic Dislocation
  - Fault (vertical displacement)
    - Genetically
      - Tension
      - Compression
    - Structurally
      - Drop (gravity)
      - Thrust
  - Shift (horizontal displacement)
    - Genetically
      - Tension
      - Compression

H. L. FAIRCHILD.

REVIEWS

Special Report on Lead and Zinc. By E. HAWORTH, W. R. CRANE, A. F. ROGERS, and others. University Geological Survey of Kansas, Vol. VIII, 543 pages, 66 plates.

While bearing the imprint 1904, this volume has only recently been distributed. It was greatly delayed in printing, and is accordingly in a few particulars out of date. It consists of three parts: (1) A discussion of the ore deposits and geology of the Kansas lead and zinc field by Dr. Haworth; (2) a brief account of the mining and milling methods of the district by Mr. Crane, and (3) an excellent discussion of the minerals of the deposits by Mr. Rogers. The interest of geologists will be mainly centered on Dr. Haworth's portion of the report, although Mr. Rogers' paper is so full and evidences such attention to detail as to probably make it standard for some years.

In Kansas the lead and zinc deposits occur in an extension of the well known Joplin field. All the productive mines are in the Galena district of Cherokee County. There are a number of sporadic occurrences of the minerals in the Coal Measure limestones and shales at other points in the state, and these are interestingly described. They are not believed to have any economic importance, but have a possible bearing on theories of the genesis of the ores. In general, Dr. Haworth does not attempt a complete independent discussion of the geology of the area. Treating it as but a portion of the great Ozark region he wisely avails himself of published sources and quotes generously from Winslow and others. He adds certain interesting local details, particularly well records, as well as a pertinent and discriminating discussion. In his conclusions as to the genesis of the ores he is more nearly in harmony with Winslow than with

Van Hise and Bain, summarizing his objections to the conclusions of the latter as follows:

(*a*) It is probable that the Missouri-Kansas area does not contain as many nor as great faults and fissures as Jenney and Van Hise and Bain have claimed.

(*b*) It would seem to Dr. Haworth that the influence of a shale bed below the ore-bearing formations has been overemphasized because, first, drilling shows that it is usually thin or absent; second, limestone lying between shales of the Coal Measures to the north and west do not contain notable amounts of ore; and third, the shale if present is by hypothesis badly fissured, and hence only an imperfect barrier.

(*c*) Evidence is produced to show that the ground water of the mines is not so entirely artesian in effect as has been claimed, especially by Bain.

(*d*) The argument built up on the presence of dolomite in the ores as indicating their derivation from below is objected to, since in the absence of an adequate explanation of the origin of the dolomite in the Silurian and Ordovician, it may quite as well be original as introduced in the Carboniferous limestones. It is further urged that the small amount of magnesia present in the normal Carboniferous rocks of the region may by concentration have given rise to the dolomite in question. Finally, the complete absence of dolomite in the very important ore deposits found in the chert is cited.

(*e*) The almost total absence of barite in the deposits, though common in the supposedly parent deposits of the Silurian, is urged as a further objection.

(*f*) Having in mind the great abundance of lead and zinc ore scattered through the Coal Measure shales and limestones, a similarity of origin is suggested. This amounts to residual and secondary concentration as proposed by Winslow, with only minor contributions through an artesian circulation.

It is interesting to note how closely Dr. Haworth's results correspond to those reached by Messrs. Buckley and Buehler from a study of another part of the same region.[1] Together

[1] The Geology of the Granby Area. Vol. 4, 2nd ser., Missouri Bureau of Geology and Mines, 1906.

they indicate a considerable change of opinion as to the emphasis to be placed on various phases of the admittedly complex process of ore generation in this district.

Since considerable additional data has become available since 1900, when the reviewer worked in the area, he may be pardoned for considering them in detail. In doing so he has no desire to make a general argument for his own views which are already in print,[1] but merely to state how far in his opinion the objections here urged are valid. He therefore passes by all other points. That later work should find corrections to be made in a preliminary report is to be expected. How extensive they may prove to be probably can only be determined on the completion of the full studies of Siebenthal, Buckley, and others, now under way in the area.

(*a*) The point with regard to faults has already been admitted as good, and an adequate explanation of the puzzling phenomena of the field has been supplied by Siebenthal.[2] It may be pointed out, however, that full admission of the point made by Dr. Haworth does not preclude attaching considerable importance to such faults as are admittedly present.

(*b*) There has been some misunderstanding of the argument based on a lower shale. Granted that in the Joplin area the shale is thin, is partially replaced by a brittle limestone, or is even in places entirely absent, these statements simply emphasize the fact that in this area there was an opportunity for underground waters in the Carboniferous and the lower rocks to mingle, and in this very significant detail the area differs from other similarly situated areas around the flanks of the Ozark uplift, where part or all of the other conditions necessary to ore depositions were present. There is, I believe, no dispute as to the general presence of an important shale bed at this horizon elsewhere in the Mississippi Valley. If the artesian theory of a

[1] Preliminary Report upon the Lead and Zinc deposits of the Ozark Region, by Van Hise, Bain and Adams. Twenty-second Annual Report, U. S. Geol. Surv., Part 2, pp. 23–227.

[2] "Structural Features of the Joplin Area," Economic Geology, Vol. 1, pp. 119–128, 172–174.

first concentration be correct, and if further the faulting in the Coal Measures be small, the similarly situated Coal Measure limestone to the northwest would not be expected to contain as large bodies of ore as the limestone at Joplin because of smaller amounts of artesian water from the lower rocks penetrating them. The origin of the ores actually found in them will be discussed later.

(*c*) Dr. Haworth's studies of the ground water are among the most interesting of his contributions. Under his directions Mr. McClaire made estimates based upon pumping and rainfall records over certain tracts of ground. This is exactly the sort of study needed, and the results are most welcome. While they can not be considered as absolutely accurate, and certain assumptions enter into the calculations, they show that there is in this case a measureable contribution to the ground water from deep sources. This is estimated by Dr. Haworth at 10 per cent. Whether this exact per cent. is correct or not clearly depends somewhat upon the assumptions made, and the figure given is evidently conservative. Prior to these measurements there were no exact data available. Statements made by many mine superintendents and managers seemed to make clear that throughout the region, if one eliminated the disturbing factor of old open works and surface drainage, there was still a common steady flow of water to be pumped in both wet and dry seasons, and this was pointed to as a reason for assuming a source of the water outside the district. This conclusion has been sharply challenged[1] and it is therefore interesting to have this confirmation as well as the quoted opinion of so careful and experienced an operator as Mr. George Playter (p. 100) that one of two adjoining areas west of Joplin is not affected at all by local rainfall. That any district or mine with large old workings or crevices open to the surface will have more water during local wet weather is obvious. Assuming the correctness of Dr. Haworth's estimate, it may be pointed out that even if the amount of water

[1] "The Geology of the Granby Area," by E. R. Buckley and H. A. Buehler, Vol. 4, 2d ser., Missouri Bureau of Geology and Mines, 1906.

contributed from the deeper horizons be smaller than that of local origin, it is quite possible for it to be the more significant. It is recognized that an argument based on this differs materially from that advanced in 1900.

It may also be pointed out that in the case of an artesian pressure from below waters from above could not penetrate far and such mingling as might occur must necessarily have been near the surface. It is not believed that the mingling could have been as widespread or as continuous as held by Dr. Haworth, but as to this more exact data is needed. His observations that to the northwest the artesian head is defective is an excellent reason for believing that leakage from below at Joplin is important. The question raised relative to the sufficiency of the feeding ground is valid, and warrants further topographic and geologic investigations at Cedar Gap and throughout a wide area to the east before a definite answer is given.

(*d*) The argument based upon the presence or absence of dolomite has possibly been misunderstood. With a fraction of a per cent. of magnesia in the normal Carboniferous rock of the area it is quite possible for dolomite to have been formed during the decomposition of such rock. Indeed it would require less concentration to have afforded the dolomite by this means than to have built up the large lead and zinc deposits from the minute quantities of these metals, also fairly to be assumed to have been disseminated through the Carboniferous limestones. Again, however, attention should be directed, not at this possible explanation, but at the broad fact that similar limestones of similar age have in fact been decomposed widely throughout the Mississippi Valley by the very process postulated without producing, so far as is known, a single workable deposit of either lead or zinc. Small quantities of blende are found in the Geode shales of the Keokuk formation in Illinois and Iowa, as well as Missouri, but no bodies of either dolomite or of ore occur in the limestone, except in this area or in north Arkansas. Furthermore, the argument for secondary introduction of the magnesia built up on the distribution of the dolomite along cracks and fissures is believed to be good and sufficiently excludes the dolo-

mite in question from the regional dolomite of earlier age, or even certain bedded dolomites found in the Carboniferous, south of Carthage.

It is in the main true that dolomite is not present in the very important ore bodies found in the flint. If, however, magnesia were carried in the ore solutions, it might well fail of precipitation when in contact with a chert and be precipitated in volume where limestone formed the country rock.

(*e*) The general absence of barite is indeed striking. Some is occasionally found and to that extent breaks the force of the argument. Possibly if more were known as to the forms in which barite may be carried in solution and the conditions under which it is precipitated, an adequate explanation would appear.

(*f*) The small amounts of lead and zinc found in the Coal Measures may be less significant than is urged. The Coal Measures evidently were formed from pre-existing Ozark rocks, and it seems necessary to believe that some lead and zinc was transferred in the process. That not much was so transferred would seem probable from the fact that in eastern Iowa, western Illinois and in Kansas, where many feet of Coal Measure strata have been cut away by erosion, no great bodies of lead and zinc have accumulated in the nearest and presumably most receptive limestones. That residual concentration has been a factor in the general process, that it may have been the only factor in the case of the Coal Measure deposits and a few others, may be freely admitted without altering the fact that the main district affords certain peculiarities not adequately explained by it alone. In considering this aspect of the case in 1900 an earnest attempt was made to discriminate between the blende formed by secondary enrichment and that due to first concentration, but without complete success. There seemed then to be no criteria universally applicable, and so both factors were taken into the explanation, as Dr. Haworth does now, though with very different emphasis on the two. A wholly satisfactory adjustment of emphasis is probably still impossible. The reviewer would be the last to urge that either residual concentration or secondary enrichment have not been important, but he has so far failed to see any ade-

quate reason for changing his belief that a first concentration by an artesian circulation was also important.

H. F. BAIN.

The Mineral Industry During 1905. Volume XIV. Edited by W. R. INGALLS. Engineering and Mining Journal, 1906.

The publication of this annual has come to be one of the eagerly anticipated events of the year, and as each succeeding volume displaces its predecessor on the shelf of chosen books which are nearest at hand, we feel distinctly better equipped. In running through the pages of Volume XIV, one is struck again with the large amount of patient work which has gone into the compilation and revision of the data presented. That any one can be found who will devote the necessary time to it, speaks well for the professional interest of the editors and publishers. A still more commendable feature is the large number of busy men scattered throughout the world, who have found time to write something for the volume. Such a spirit of co-operation and such a free giving of scientific and technical data is the very foundation of the rapid progress of the mineral industry, and Mr. Ingalls and his immediate collaborators may well feel honored to have been the means not only of bringing together this large amount of data but even more of being the center of so large a co-operative movement among engineers.

From Aluminium to Zinc, through some 600 pages, the statistics, technology and trade of the individual metals and minerals are ably reviewed. By way of good measure there are added some 40 pages of discussion of "Ore Dressing and Coal Washing" by Professor Richards, 16 pages on "Improvements in Sampling and Assaying," by Hofman, and finally a 65 page statistical review by countries from Australasia to the United States. These special pages are only the minor part of the text. Scattered throughout the book, connected with the statistical reviews are the usual summaries and first hand discussions of various phases of the mineral industry. The volume has long been known not only for its abstracts and summaries, but for the surprising

number of very brief papers, not elsewhere available, covering various phases of technology. If this volume be contrasted with its predecessors it may be noted that relatively more space is devoted to metallurgy and technology and less to prices, mining discoveries, and to economic geology. The customary review of progress on ore deposits by Professor Kemp is missing.

It is an interesting comment on how rapidly we are moving and how short a distance it is given us to see into the future, that the Cobalt district is here given a mere page, though the editorial work was not closed until May, 1906. The Illinois petroleum fields, producing now about half as much as those of Indiana, are given a short paragraph, and seemingly do not enter at all into the statistics of production (p. 469). In 1905 they shipped 156,000 barrels. There are minor errors and omissions, usually not important. Hannibal is located on the Missouri instead of the Mississippi River (p. 66), which if true would influence freight rates materially; Mexico is in one place (p. 139) referred to as the "most important copper producing country in the world"; the calamine in the Joplin district is said to be "entirely" silicate (p. 562), etc. The development of the Boulder County fluorspar mines, which now supply the Colorado Fuel and Iron Company furnaces, began in 1905 and might well have been included in Mr. Foh's excellent review of fluorspar production. Other omissions occur, but after all they merely emphasize the large amount of good things not omitted.

There is in some cases a rather curious lack of balance. For example, 22 pages are devoted to tin while only 29 can be spared for coal and coke and seven for cement. It would seem that a slightly better distribution of the limited space might in such cases be made. It is well established, however, that the teeth of a gift horse should not be closely examined, and a gift this is, whether we consider it from the point of view of the nominally paid contributor, the overworked editor, or the generous publisher, each of whom has made his contribution. To all of them the reviewer, and in this he is persuaded he speaks for many others, presents his best thanks.

H. F. Bain.

Turmalinführende Kobalterzgänge. By OTTO STUTZER. Zeitschrift für praktische Geologie, Bd. 14, 9 Sept., 1906, pp. 294–298.

Stelzner and von Groddeck many years ago described veins containing tourmaline in association with copper ores from Tamaya and Las Condes in Chile. The author of this short paper adds to this an occurrence of cobalt ores, containing quartz and tourmaline from San Juan in the Department of Freirina, Province of Atacama, Chile. Some copper ores are also present in the veins which are contained in amphibolitic schists and dioritic rocks. Although the ores are generally oxidized it can be shown that cobaltite was the original mineral. The paper closes with an enumeration of the different classes of tourmaline bearing ore deposits known to date. They are as follows: Cassiterite veins, copper veins, copper-gold-quartz veins, cobalt-copper veins, siderite veins, and finally specularite-magnetite veins. The latter two are deposits of unusual character which have lately been described from Styria and from the Vosges.

W. LINDGREN.

Padron Minero de los Territorios Nacionales 1890–1905. Annales del Ministerio de Agricultura. Tomo 1 Num. 3 Division de Minas, Geologia y Hidrologia. Buenos Aires, 1906, pp. 83.

As indicated by the title this book enumerates the mines and mining claims in the national territories, mostly situated in the western and southern part of the Argentine republic, but does not describe the mining regions in the older provinces. The list indicates the general character of mineral, the owner, and the mining district, if established, and is accompanied by seven plates giving rough maps of the territories which in order from north to south are as follows: Los Andes, La Pampa, Neuquen, Rio Negro, Chubet, Santa Cruz and Tierra de Fuego.

Deposits of copper, silver and gold are shown to exist in various parts of the eastern Andean slope, especially in the territory of Neuquen, about on the latitude of Conception in Chile, but apparently little is done in the way of exploitation. Saline deposits also occur, among these especially borates in the most

northerly territory, Los Andes. The greatest interest attaches to the extensive list of gold placers in the extreme southern end of Santa Cruz and on the Tierra del Fuego. The western part of the island of Tierra del Fuego belongs to Chile. Little or no geological information is given.

W. LINDGREN.

The Copper Deposits of the Robinson Mining District, Nevada. By ANDREW C. LAWSON. University of California Bulletin, Department of Geology, Vol. 4, No. 14, pp. 287–357.

This bulletin contains a very valuable and timely description of the geological features of what is commonly known as the Ely district in the Egan Range, in the center of White Pine County, some fifty miles west of the Utah state line. The attention of the mining world has lately been directed to this district by reason of the discovery of large masses of low-grade chalcocite ore. A railroad about 140 miles long has recently been built into the camp southward from the station of Cobre on the Central Pacific line, and several companies are preparing for operations on a large scale, notably the Nevada Consolidated Copper Company, the Giroux Consolidated Company and others. It is reported that production will begin about the end of 1907. It is to be regretted that the geological map which should have accompanied the paper was destroyed in the San Francisco fire. A sketch map would have proved an acceptable substitute.

The Egan Range trends north and south and has a width of several miles; on both sides it is separated from neighboring parallel ranges by broad alluvial valleys. It consists chiefly of sedimentary rocks ranging from the Cambrian to the Carboniferous, which have an aggregate thickness of many thousands of feet, and have been compressed in part into open folds, in places affected by faulting. Pre-Cambrian basement rocks are not exposed, but there are many intrusive masses of granitic and monzonitic rocks, probably of Mesozoic age. At a later date local intrusions took place of a light-colored, acidic and porphyritic rock which have since been much kaolinized and silicified. The important ore bodies occur in these rocks. The bordering lines

of the range are apparently not determined by fault lines. Late Tertiary rhyolites and tuffs complete the list of the principal rocks.

The Ely deposits are situated in a pass of the range, and the mining district comprises a belt about one mile in width and having a length across the range of six miles. The deposits are intimately and genetically connected with an irregular mass of "porphyry" cutting Carboniferous rocks and occupying the center of the belt. Ore deposits are found both in the porphyry and in the surrounding sedimentary mass. The main bodies of copper ore are in the porphyry, while as yet not fully exploited silver-lead ores occur in the limestones. There are also gold deposits in the sedimentary rocks, notably at the Chainman and Saxton mines, which, however, are idle at the present time.

The copper ores center at the Ruth mine on the east, at Copper Flat in the middle part, and near Pilot Knob at the west end of the district.

The elevation ranges from 6,440 to 8,040 feet.

Professor Lawson divides the sediments as follows:

CARBONIFEROUS:

Ruth Limestone.—Thickness 500 feet or more. Bluish-gray, heavy-bedded, cherty limestone.

Arcturus Limestone.—Thickness 1,000 feet. Yellowish, shaly or sandy limestone.

Ely Limestone.—Thickness 1,500 feet. Thick-bedded, cherty lilac gray limestone.

Upper Carboniferous fossils were found in the Ruth limestone.

DEVONIAN:

White Pine Shale.—Thickness 1,000 feet. Blue-black argillaceous shale, sometimes white or creamy by solfataric alteration. Included in this shale is a number of light gray limestone about 150 feet thick.

Nevada Limestone.—Thickness 1,000 feet or more. Massive gray or black limestone.

No fossils were found in the Devonian, but a satisfactory correlation was established with the Eureka section in the ranges

adjoining on the west, which have been studied by Hague and Walcott.

The dominant structural feature is a broad northwardly-pitching syncline, the axis of which runs north and south through the Ruth mine.

The monozite occupies an area about one mile by half a mile near Rib Hill, and underlies the low and sloping ground of Weary Flat. The intrusive character of the flat-topped monzonite mass is established with considerable elevation. The contact metamorphism is marked, converting the shales into hornfels and limestone into garnet rocks with chalcopyrite. Many prospects have been opened in the latter. The age of the monzonite is established as post-Carboniferous.

The rock consists of orthoclase, andesine and hornblende in hypidiomorphic granular structure, with apatite, magnetite, and titanite as accessories. From a complete analysis by Herbert Ross it is seen that the rock contains 61.69 per cent. SiO_2; 5.49 per cent. CaO; 3.05 per cent. Na_2O, and 3.88 per cent. K_2O.

Great interest attaches, of course, to the copper-bearing porphyry, which is stated to be distinctly different from the monzonitic rocks. It occupies two areas. The first extends east-west for three miles, with a maximum width of a little less than one mile, and reaches from Copper Flat westward to Rusty Ridge. The second area extends from Ochre Valley eastward to a point near the Chainman mine. These two areas lie in an east-west alignment, and this belt has determined not only the distribution of the copper deposits, but also the general physiographic features of the district.

Structural evidence establishes the intrusive character and indicates the laccolithic nature of the igneous bodies. They seem to lie on the White Pine shale as a warped sheet partly removed by erosion, and it is probable that the upper sedimentary formations once arched across them completely. The strata were folded before the intrusion of the porphyry.

The evidence is confirmed by the presence of contact metamorphism in the adjoining limestones, which are changed to yellowish green garnet rocks, with magnetite and limonite. From the

description it appears that exposures of unoxidized rocks are not abundant. The garnets appear as usual in crystals of zonar structure and often decided birefringence. Other observed minerals are calcite, quartz, and epidote. Chalcopyrite is not mentioned, although to judge from the following paragraphs it must also be present in the contact metamorphic rocks. All of the observed occurrences of the contact rocks are on the lower side of the porphyry mass. Professor Lawson regards the garnet rocks as due to a reaction between the intrusive porphyry and the limestone by means of an aqueous solution from the porphyry which contained the silica that eliminated the carbon dioxide from the limestone. It is not stated whether the garnet is a grossularite or an andradite; in the latter case the question of the derivation of the iron would necessarily present itself. We also miss a statement regarding the approximate composition of the limestone. The author is inclined to look for the origin of the iron ore in a later leaching of the igneous rock and not in a direct reaction of the molten magma upon the limestone.

[In many similar occurrences it has seemed to the reviewer entirely impossible to separate the question of the origin of the garnet, epidote, magnetite, and chalcopyrite; all are intimately intergrown and were simultaneously formed.]

The porphyry cuts the earlier monzonite and modifies it at the contact in a peculiar way; the author attributes this to a downward leaching from the younger porphyry.

The porphyry is extremely altered and bleached, and fresh rock is almost impossible to obtain. The best material obtained from the head of Lane Valley shows a bluish-gray color, a dense matrix in which are embedded small phenocrysts of dull feldspar and other fresher feldspars up to half an inch in length. Much calcite is present. The groundmass is a holo-crystalline aggregate of untwinned feldspar with some quartz and much calcite. The small feldspar crystals are thoroughly decomposed, and the large orthoclase crystals also contain calcite. A little bleached biotite and grains of pyrite in the groundmass complete the list of minerals. Fluorite occurs in places.

In other specimens the decomposed phenocrysts are embedded in a matrix of silvery-white felted scales which the author interprets as kaolin. The feldspar phenocrysts are often represented by an aggregate of white mica scales and quartz. Portions of the rocks contain abundant seams of pyrite and chalcocite, and constitute the commercial ore.

The chemical composition of the porphyry is difficult to ascertain on account of extensive secondary changes. The least altered material from the upper end of Lane Valley was analyzed by Herbert Ross, with the following partially quoted result: SiO_2, 58.31; Al_2O_3, 16.69; MgO, 1.27; CaO, 5.29; Na_2O, .20; K_2O, 6.11; P_2O_5, .31; Fe, 2.27; S, 2.79; CO_2, 3.47; H_2O, 2.42. The author finds that this corresponds approximately to the following mineralogical composition:

Orthoclase	37
Albite	1.5
Anorthite	2
Biotite (residues)	3.5
Apatite	.6
Kaolin	22
Pyrite	5
Quartz	20
Calcite	8
	99.6

His conclusions are that the rock was originally a holocrystalline rhyolite altered by kaolinization, silicification, carbonatization, and pyritization, water, sulphur, and carbon dioxide having been introduced from outside sources.

It is to be regretted that no analysis of the ordinary altered porphyry is presented, which would permit a closer examination of the processes of alteration. It seems to the reviewer that the above analysis, by its lack of sodium, richness in potassium, and its general aspect, clearly indicates the presence of a considerable amount of sericite, and that Professor Lawson has laid undue stress on the kaolinization at the expense of sericitization. It is well known that the formation of chalcocite is accompanied by that of some kaolin, but it is usually found that this has been

preceded by a general sericitization of the rock. In the above analysis, if the whole amount of the water is allowed for kaolin we would only have a little more than 17 per cent. of that mineral instead of 22, as given by Professor Lawson.

In the porphyry, or on its periphery, occur large masses of quartz which largely are caused by replacements. These masses Professor Lawson states are called "blow-outs" by the miners, and in contradistinction to the quartz in veins he adopts for them the modified word "blouts;" this appears an unfortunate term, which will scarcely find general acceptance; it is not defensible from an etymological standpoint, and, moreover, "blow out" is a term cheerfully applied by miners to any large mass of quartz entirely irrespective of whether it is a vein or not. Near the Ruth mine considerable areas are occupied by these masses of quartz; most of them lie on the contact between the porphyry and the limestone roof of the probably laccolithic intrusion. Other quartzose bodies occur wholly in limestone. The quartz is compact, brecciated or cellular, generally resembles a quartzite, and bears evidence of a product of replacement partly of limestone or of the contact metamorphic rocks or of the porphyry. It sometimes contains copper stains, pyrite, chalcopyrite, and garnet.

Certain parts of the porphyry contain so much copper as to constitute an ore. The oxidized upper zone contains practically no copper, but at a varying depth of from 100 to a maximum of 500 feet from the surface, sulphide ores of chalcocite and pyrite are met. The water level at the Ruth mine stands about 335 feet below the surface. This probably implies a lowering of the water level of the district of not less than 250 feet, at such a rate that the oxidation process failed to keep pace with it, so that a couple of hundred feet of the unoxidized zone has been left stranded above the water plane.

An analysis of the mine water shows that it chiefly contains sulphates of calcium, ferrous iron, magnesium and potassium; in all 64 grains per gallon. Nearly all of the iron is present as ferrous sulphate; in a carefully taken sample there was only 0.4

grain of ferric against 9.36 of ferrous sulphate. This interesting analysis confirms the belief expressed by the reviewer in the Clifton report (Prof. Paper No. 43, U. S. Geol. Survey, p. 179) of the general absence of ferric salts in the chalcocite zone. The author believes that this deficiency of oxygen promotes the maintenance of a supply of SO_2, which, as shown by Winchell, is favorable for the reduction of copper sulphate to cuprous sulphide. No SO_2 was, however, discovered in the water, and its existence in the chalcocite belt seems to the reviewer extremely problematical. (See E. & M. Journal, Vol. 79, p. 189, 1905.)

The chalcocite is secondary relative to the pyrite and appears frequently as a shell surrounding the latter. A very interesting experiment on the leaching action of ferrous sulphate is recorded. A 10 per cent. solution of ferrous sulphate was allowed to percolate through a mixture of chalcocite and porphyry in the presence of the atmosphere. Copper was taken into solution and passed through the filter as copper sulphate at a fairly rapid rate.

While the secondary enrichment of the porphyry below the zone of oxidation is unquestionable, the products of this enrichment are not thus far localized at any particular horizon in the porphyry, and the richest parts are rather determined by the freedom of flow of descending water than by any horizontal control, such as the present level of the ground water. The author believes that the chalcocite zone will descend with a moderate enrichment of the ore underneath the level of the ground-water, and then gradually decrease in value with depth. A comparison with Clifton, where the pyritic ores are met high above the ground-water level, will prove interesting.

The question of the original unenriched copper deposits from which the chalcocite ores were derived is then entered upon. The only primary copper deposits in the district are limited bodies of chalcopyrite associated with garnet rock. Some of them at the monzonite contact are clearly contact deposits caused by solutions bearing silica, iron, and copper derived from the molten intrusive mass and reacting upon limestone.

But there are also primary copper ores in the quartz masses

associated with the copper-bearing porphyry, and it is probable that these are caused by silicification of garnetiferous limestone near the contact. It is suggested that the chalcocite ores of the Ruth mine are derived from downward leaching of copper from the quartz bodies in which they were originally deposited, and deposited in the porphyry at a time of considerably higher water level. The lowering of the latter caused solution of the chalcocite and re-deposition at lower levels.

The average ores at the Ruth mine (Nevada Consolidated Copper Company) contain about 10 per cent. of pyrite and at least 3.25 per cent. of chalcocite. At Copper Flat similar conditions prevail, except that part of the copper has here been deposited as carbonates in the oxidized zone, probably owing to more liberal supply of carbon-dioxide. As at Ruth, there is a certain depth of dry sulphide zone, but the chalcocite extends here, too, below the water level.

There is little evidence of compressive stress in the rocks of the region, but the ore-bearing porphyry shows a strong system of slips and shear zones, which generally dip northward at moderate angles. The intensely broken and sheared porphyry contrasting against the unmoved condition of the surrounding country is explained by Professor Lawson as the result of shrinking, due to the kaolinization. Theoretically, kaolinization, as well as sericitization, should be accompanied by a shrinkage of volume of 12 to 15 per cent., but the reviewer openly admits that he has never seen any field evidence confirming this. The tendency towards contraction is, in fact, probably more than balanced by the greatly increased porosity of the rock.

The following hypothesis for the origin of the copper ores is advanced by the author: Water containing carbon-dioxide rose in and about the recently consolidated porphyry, the ascending tendency being due to the disturbance of the equilibrium of the ground-water by the invasion of the intrusive mass. This ascending water would inaugurate the kaolinization of the porphyry. The potassium silicate liberated by the kaolinization reacting upon the bicarbonate of calcium in the ascending waters would

give calcium silicate, which again by decomposition by carbon-dioxide would yield silica. Thus the quartz masses of the "blout" are accounted for. Moreover, since calcium silicate is formed in the process outlined above, it may have been locally precipitated in combination with iron on the periphery, and so give rise to the garnet rock at the contact with the limestone. "There seems little escape from the conclusion" the author says, "that the copper was originally minutely disseminated through the porphyry in its unaltered condition, and that the same ascending waters which robbed the porphyry of part of its silica to form the quartz "blout" also leached it of its copper, depositing it as chalcopyrite in the "blout," whence, by oxidation and the agency of descending waters, it was carried down into the porphyry again and deposited as chalcocite, the permeation of the rock by such descending waters being greatly facilitated by the rupture and collapse of the mass, due to koalinization."

This hypothesis presents some interesting features. It will be noted that the author in one case admits contact metamorphic deposits of chalcopyrite and garnet derived from solutions containing silica, iron, and copper, given off by the molten magma, and in another case calls on atmospheric waters ascending through the recently consolidated porphyry to effect an entirely similar change. Moreover, garnetization and kaolinization are not processes which would be apt to be carried on side by side. Neither is it apparent why these ascending solutions should not have deposited chalcopyrite and pyrite in the porphyry with simultaneous sericitization, such as generally takes place under influence of hot waters. The cases of kaolinization caused by hot waters have a decided tendency to dwindle under careful examination. Professor Lawson's conception of the origin of the pyrite in the ore is not clearly expressed. The reviewer thinks it probable that lean pyritic ores will be found below the chalcocite zone and that the slow oxidation and degradation of these ores is responsible for the chalcocite zones, no doubt aided by the oxidation of the lean products of contact metamorphism at the upper contact.

The last pages describe two dikes of minette which occur at

the Ruth mine and are of importance inasmuch as in some places they limit the extent of the ore body. The fine-grained rocks consist of orthoclase and biotite, with some accessory corundum. Rhyolitic lavas and tuffs occupy considerable areas at Quarry Hill and White Hill.

The faulting occurring in the district is of later date than the rhyolite flows, but of no particular importance in regard to the mineral deposits.

The silver deposits in limestone are briefly mentioned. The author concludes that near Ruth there are three well-marked zones of deposits, as follows:

1. A central one containing pyrite and chalcocite in the porphyry.

2. A southern one carrying gold in the limestones below the porphyry.

3. A northern one carrying argentiferous galena with some zinc and copper sulphides in the limestones above the porphyry.

W. LINDGREN.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

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G. F. LOUGLIN AND F. H. MOFFIT.

METALLIFEROUS DEPOSITS.

COBALT.

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SCIENTIFIC NOTES AND NEWS[1]

THE ANNUAL MEETING of the Iron and Steel Institute will be held in London, England, on the 9th and 10th of May, 1907.

A CIRCULAR issued by the secretary of the American Institute of Mining Engineers announces that the ninety-second meeting of the Institute will be held in New York City, on April 18, 1907. The annual business meeting of the corporation was held in New York, on February 19, 1907. The meeting scheduled for April 18 will be devoted to the reading of papers. Further particulars will be given in a later circular.

The removal of the executive offices of the institute to the new building necessitated the constant presence of the officers in New York City and have made it impracticable for them to arrange a meeting away from New York. This is the less to be regretted as the formal dedication of the new building will take place on April 16 and 17, immediately preceding the session for the reading of papers, so that those who attend the ceremonies may remain for the regular meeting without the necessity for a special trip later on in the year.

THE DEATH OF DIMITRI IVANOVITCH MENDELEEF at St. Petersburg, on February 2, 1907, has removed from the ranks of scientists one of the most celebrated chemists of the nineteenth century. Professor Mendeleef was born at Tobalsk, Siberia, in 1834, and was at the time of his death seventy-three years of age. In addition to his discoveries in chemistry, so well known that their mention is hardly necessary, he was a geologist and prominent in educational circles. He received last year at the meeting of the Royal Society the Cowley gold medal.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

GEOLOGISTS have learned with regret that Charles D. Walcott, for thirteen years director of the United States Geological Survey, has tendered his resignation and accepted the position of secretary of the Smithsonian Institution, to which he was elected on January 23, 1907.

Mr. Walcott was born at New York Mills, N. Y., on March 31, 1850, became assistant in the New York State Surveys in 1879, and was appointed assistant geologist of the United States Geological Survey in 1879. In 1894 he was appointed Director of the Survey, succeeding Major J. W. Powell, and has filled that position with remarkable success up to the present time.

It will be difficult to fill the position he leaves vacant and, however able his successor may prove to be it is doubtful whether he will meet with as great a measure of success in his administration of office.

F. H. NEWELL, chief engineer of the Reclamation Service, has been elected president of the Washington Society of Engineers.

MR. W. J. PETERS is this year again in command of the Magnetic Survey yacht *Galilee* which is engaged in the magnetic survey of the Pacific Ocean under the auspices of the Carnegie Institution. The vessel left San Diego, Cal., December 22, on a cruise of 22,000 miles to extend through 1907 and make a circuit of the North Pacific, touching at Shanghai, Hongkong, Yokohoma, Honolulu, Dutch Harbor and Sitka.

MR. ERNEST HOWE of the U. S. Geological Survey, who is geologist of the Isthmian Canal Commission, left New York for Panama, January 22, to spend the following three months in the canal zone. He is accompanied by Sydney Paige, also of the Geological Survey. Mr. Howe has been conducting some experiments in cement-making with the view to obtaining a composition which will not be affected by sea water. One of the difficulties in the concrete construction on the canal has been the rapid disintegration of the concrete by the solution of the cement where it is in contact with salt water.

MR. J. E. SPURR was in Washington a part of the month of January and returned to Mexico the 21st.

LEWIS E. AUBURY has been reappointed State Mineralogist of California. Mr. Aubury was first appointed to this post April 23, 1901, and held it for a period of four years. His ability has been justly recognized in his reappointment.

A. C. LAWSON, of the University of California, who is a member of the California Earthquake Commission is spending part of the winter in Washington, D. C., preparing a report of the San Francisco earthquake for publication by the Carnegie Institution. The conclusions reached by the Commission will govern somewhat the reconstruction of San Francisco and other cities on the fault line. It is to be hoped that permanent buildings will not again be built on made ground for the recent catastrophe proved that the intensity of movement is greatest in soft ground.

THE FUEL TESTING PLANT of the U. S. Geological Survey which has been in operation at St. Louis since 1904 is being demolished and will be moved to the Jamestown Exposition. The plant has a contract to supply the exposition with 25 per cent. of the power used in running the exposition. Instead of testing carloads of coal from all over the United States the work at Jamestown will be confined to tests of two or three of our most prominent eastern coals. There will be three types of briquetting plants in use: the English type, furnished by William Johnson & Sons, Leeds, England; the German type made by Maschienenfabrik Buckau, of Magdeburg, Germany; and the American type, furnished by Renfrow Briquet Machine Co., of St. Louis. The German machine is to test Texas lignite shipped by sea from Galveston. All machinery used and all coals tested at the Fuel Testing Plant are furnished to the government free of charge.

IN VIEW OF the possible exhaustion of the coal supply in the United States within the next 200 years as predicted by M. R. Campbell, the present investigation of the waste in mining and preparation of coal for market being conducted by E. W. Parker, of the U. S. Geological Survey, should be of general interest. Wasteful methods of mining in some districts are leaving tremendous quantities of coal in the ground as pillars. Where

rooms are too wide the burden squeezes and crushes the pillars so that they cannot be drawn. A more economical method is the driving of narrow rooms with wide pillars so that there will be a minimum of squeezing and the pillars can be robbed clean. A serious waste in some of the western Pennsylvania fields is the leaving in the mine of the upper or lower portion of the bed because it is slightly inferior to the rest. Operators desiring only a coking or gas-producing coal leave unmined hundreds of thousands of tons of good steaming coal which is lost beyond recovery when the mines are abandoned. Another serious problem is to find a use for the slack which forms a considerable percentage of the output of some fields. One company in the Middle West is shipping 1,200 tons of coal daily and putting 600 tons of slack on the dump. This involves not only a great loss of fuel but it costs 65 cents a ton to get it out. It has been found that slack which has been flushed back into some of the Pennsylvania mines for gobbing runs as high as 95 per cent. fixed carbon. Under these conditions the necessity of developing a successful method of using pulverized fuel for steam raising is very apparent. A third extravagant and wasteful practice which means the loss annually of millions of dollars is that entailed in the manufacture of coke in beehive ovens. The by-products which now are dissipated in the air by the thousands of ovens in Pennsylvania and West Virginia could be saved by the use of retorts or by-product ovens and it would no longer be necessary to import ten million dollars worth of ammonia and tar products every year. It is hoped that by bringing the results of Mr. Parker's investigations before the public less wasteful methods will be adopted and schemes will be evolved for the successful use of what now is a total loss.

AT THE MEETING of the Geological Society of Washington, held Wednesday evening, December 19, the following officers were elected for the ensuing year: President, Waldemar Lindgren; vice-presidents, M. R. Campbell, A. H. Brooks; treasurer, J. A. Taff; secretaries, F. E. Wright, Ralph Arnold.

WESTERN COAL FIELDS have received a large amount of at-

tention from the U. S. Geological Survey during the past season. As yet these extensive fields are but little developed and in some cases only slightly known. One of the large fields in Colorado has been under investigation by Mr. H. S. Gale for the past two years and he has now in hand a considerable amount of information concerning an area which promises to provide fuel for the State of Colorado for hundreds of years and have some to spare for less fortunate neighbors. Mr. Gale and his party studied the Yampa field in northwestern Colorado last year and the final report is now in print as Bulletin 297. This year he carried a detailed topographic and geologic survey over an area of 1,000 square miles extending south from the Yampa field through portions of Rio Blanco and Garfield counties in what is known as the White River and Grand River coal fields. The map which is now being compiled from the field notes is on a scale of 1 mile to 1 inch and the relief is shown by 100-foot contours. There are many thick coal beds throughout the area, mostly bituminous coal, which will make an excellent steam and domestic fuel.

IN AN ARTICLE by F. L. Ransome on the Direction of Movement and Nomenclature of Faults in Vol. I., No. 8, ECONOMIC GEOLOGY, reference was made on page 782 to the Preliminary Report of the State Earthquake Commission as "Pamphlet without date or place of publication." This is, however, to be found in the letter of transmittal accompanying the report, although it does not appear on the cover.